ABSTRACT OF THESIS

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Title of Thesis "An investigation into the management and development of the oyster fisheries in Galway Bay, Ireland".

The purpose of this investigation was to produce a comprehensive account of the Clarinbridge Public Oyster Fishery, Galway Bay, which would serve as a basis for the future conservation, management and development of the fishery.

The history of the Irish oyster industry and the change in distribution and status of Irish oyster fisheries since the turn of the century are outlined and the history, landings, exploitation, management and regulation of the Clarinbridge fishery are discussed in detail.

The physical characteristics of the Clarinbridge fishery are described and hydrographical and meteorological data for the period 1968 to 1972 are presented and their influences on larvae production, spat settlement and population dynamics are discussed.

The breeding biology of *Ostrea edulis* L. is reviewed and details of the timing, distribution and intensity of larvae production and spat settlement at Clarinbridge are given. The results of spat collecting trials conducted with a variety of materials are presented and discussed in relation to their value for fishery improvement.

Detailed population studies were conducted between February 1970 and July 1972. Changes in population size and structure are described and growth rates, mortality rates and production estimates are presented and discussed in relation to fishery management.

Factors limiting oyster production at Clarinbridge, including the effects of starfish *(Asterias rubens)* predation on the oyster stocks, are analysed and discussed.

The implications of the findings presented in the thesis, in the conservation, management and development of the Clarinbridge Public Oyster Fishery, are discussed and means for implementing recommended improvements are outlined.

Finally, the thesis concludes that the Clarinbridge Public Oyster Fishery will survive in the prevailing environmental conditions and under the current exploitation/management regime. However, it is emphasized that positive management, through an organisation such as a co-operative, will be necessary if the fishery is to be prepared adequately for the rigorous competition which will develop with Ireland's entry into the European Economic Community.

Use other side if necessary

AN INVESTIGATION INTO THE MANAGEMENT AND DEVELOPMENT OF THE OYSTER FISHERIES IN GALWAY BAY, IRELAND

ANTHONY WHILDE B.Sc., M.I. Biol.

Ph.D.

UNIVERSITY OF EDINBURGH

1972

TO

MY MOTHER AND FATHER

WITH GRATITUDE AND AFFECTION

SUMMARY

The purpose of this investigation was to produce a comprehensive account of the Clarinbridge Public Oyster Fishery, Galway Bay, which would serve as a basis for the future conservation, management and development of the fishery.

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CHAPTER I

GENERAL INTRODUCTION

I. GENERAL INTRODUCTION

The genus *Ostrea* has a worldwide distribution and comprises at least 20 species (Ranson, 1950, cited by Korringa, 1952) which inhabit climatic zones from the subantarctic to the subarctic. *Ostrea edulis* L., the European flat oyster is the only species of this genus which inhabits European waters and it has been recorded in most suitable areas from Norway to Spain and also in the Mediterranean, Adriatic and Black Seas (Orton, 1937a; Tebble, 1966). It occurs most commonly in shallow estuarine areas where the seabed is firm and salinity exceeds 25 ‰ for most of the year.

During the last century many European oyster populations were decimated by overfishing, disease, alien predators, adverse weather conditions, pollution and land reclamation and neglect. Irish oyster stocks suffered a similar fate to those of Britain and continental Europe, but two important self-perpetuating public oyster fisheries have survived, as well as several private fisheries, and together these form the basis of the Irish oyster industry which will be described in more detail in Chapter II.

Several other species of *Ostrea* are exploited commercially in various parts of the world. These include *Ostrea lurida* Carpenter, the Olympia oyster, which is found on the western coast of North America from Alaska to California; *Ostrea lutaria* Hutton, a native of New Zealand (Hollis, 1963); *Ostrea chilensis* Phil. which occurs from Chiloé Island in Chile north to Ecuador (Hancock, 1969a), *Ostrea taurica* Kryn which was harvested from the Black Sea at least until 1949 when stocks began to decline (Zenkevitch, 1963).

Ostrea edulis is harvested in several countries (Table 1). France, the Netherlands, the United Kingdom and Spain are the major producers, while Norway still supplies limited quantities of oyster seed to other oyster growing nations. Small landings were once made in Sweden, Germany and Portugal, but these countries have now virtually ceased to cultivate flat oysters. Production in France, in the United Kingdom and particularly in Holland has declined markedly in recent times, largely as a result of adverse factors mentioned previously. In contrast, however, oyster production in Ireland is showing a steady and consistent increase as the demand for Irish oysters improves and private oyster fisheries are developed.

More important in terms of worldwide production are the cupped oysters of the genus *Crassostrea* (Sacco, 1897). These are physically and physiologically better adapted to living in turbid and less saline waters and can thus take advantage of the often richer food supplies and protection available in estuaries, creeks and other sheltered coastal waters. They are more easily cultivated than *O. edulis* and species such as *C. gigas* lend themselves favourably to mass production in shellfish hatcheries.

Commercially exploited species of *Crassostrea* include *C. angulata* Lam. the Portuguese oyster, which has been produced in increasing quantities since 1950 (Table 2); *C. virginica* Gmelin the American or Eastern oyster (Galstoff,

TABLE 1. LANDINGS OF FLAT OYSTERS *(O.EDULIS)* IN EUROPE FROM 1938 TO 1969*
(In metric tons)

Year	Ireland	England Wales Scotland	France	Netherlands	Spain	Sweden	Norway	Germany	Portugal	Total
1938	22	835	1,898	849	-	-	9	-	454	4,067
1939	-	-	-	-	-	-	-	-	-	-
1940	81	-	-	-	-	-	-	-	-	81
1941	48	-	-	-	-	-	-	-	-	48
1942	61	-	-	557	-	-	-	-	-	618
1943	80	-	-	477	567	-	-	-	-	1,124
1944	-	-	-	-	487	-	33	-	-	520
1945	-	287	1,949	-	309	1	27	-	250	2,823
1946	?	399	1,471	1,366	116	1	6	-	34	3,393
1947	107	339	1,496	1,150	151	4	-	-	281	5,528
1948	47	455	110	1,458	213	-	-	-	-	2,283
1949	39	407	1,700	500	400				100	3,146
1950		600	100	1,500	400	Less than 50 mt/annum	Less than 50 mt/annum	Less than 50 mt/annum	100	2,700
1951		600	100	1,300	600				100	2,700
1952		500	1,800	1,400	400				300	4,400
1953		500	1,600	1,200	300				400	4,000
1954		500	2,400	1,400	400				600	5,300
1955		500	200	1,600	500				1,200	4,000
1956		500	2,600	1,900	700				1,300	7,000
1957		500	2,900	1,900	500				500	6,300
1958		400	200	1,900	600				900	4,000
1959		400	18,800	2,100	700				400	22,400
1960		400	21,600	2,700	900				200	25,800

*Source F.A.O. Statistical Yearbooks

Table 1. contd. (ii)

Year	Ireland	England Wales Scotland	France	Netherlands	Spain	Sweden	Norway	Germany	Portugal	Total
1961		200	29,400	2,600	500				200	32,900
1962		300	11,700	2,200	500					14,700
1963		200	10,000	500	500					11,200
1964		200	9,800	600	200					10,800
1965		200	12,400	700	700					14,000
1966		200	13,000	700	400					14,300
1967	96.0	200	13,000	800	0	0	-	0	-	14,096
1968	108.0	200	14,000	800	100	0	-	0	-	16,008
1969	186.0	100	8,500	800	800	0	-	0	-	10,386

*Source F.A.O. Statistical Yearbooks

1964; Loosanoff, 1965); *C. gigas* Thunberg the Japanese or Pacific oyster (Cahn, 1950; Steele, 1964); *C. commercialis* the Sydney rock oyster (Roughley, 1933); *C. rhizophore* Guilding of the West Indies (Bacon, 1970); *C. gryphoides* Scholtheim of India (Durve, 1967); *C. rivularis* Gould of Japan (Cahn, 1950); *Crassostrea* sp. of South Africa (Stander in Firth, 1969).

A third genus of oyster, *Pycnodonta*, is widely distributed over the globe but it always occurs in deep or open seas of full salinity and is of no commercial value (Yonge, 1960).

It should be noted here that pearl-oysters of the genus *Pinctada*, whilst of some commercial value, are not true oysters but bivalves more closely related to mussels and as such warrant no further consideration in this work.

Oysters may be fished directly from natural oyster beds such as exist in Galway Bay and Tralee Bay in Ireland, or they can be grown on specially prepared layings situated intertidally or below low water mark. The stocks on a natural oyster bed are generally replenished by natural spat settlement, whilst those on privately cultivated layings are often maintained by supplies of seed from elsewhere. On attaining the desired market size and quality the oysters can be harvested in several ways which will be considered in more detail in a later section. These include hand-picking from the shore at times of low spring tides; dredging from boats, of various sizes, propelled by oars, sails or engines; a variety of other methods such as tonging, diving and mechanical harvesting, which are used only on a limited scale

TABLE 2.

LANDINGS OF PORTUGUESE OYSTERS *(CRASSOSTREA ANGULATA)* IN EUROPE FROM 1938 TO 1969. (metric tons)*

Year	United Kingdom	France	Portugal	Spain	Total
1938		17,719			17,719
1939					
1940					
1941					
1942					
1943				20	20
1944				22	22
1945		26,412		17	26,429
1946		20,159		24	20,183
1947		36,994		10	37,004
1948		5,073		26	5,099
1949		26,600			26,600
1950		19,800			19,800
1951		71,800			71,800
1952		6,100			6,100
1953		17,400			17,400
1954		14,400			14,400
1955		3,600			3,600
1956		10,000			10,000
1957		15,900			15,900
1958		12,900			12,900
1959		69,700			69,700
1960		65,900			65,900
1961		57,700			57,700
1962		64,800	2,300		67,100
1963		60,300	900		61,200
1964		52,400	10,200	9	62,609
1965	100	54,600	200	200	55,100
1966	100	49,900	300	300	50,600
1967	100	56,500	4,800	800	62,200
1968	100	29,800	9,600	100	39,600
1969	100	31,000	9,100	900	41,100

* Source - F.A.O. Statistical Yearbooks.

at the present time.

Ostrea edulis is a high priced commodity retailing at between 73p and £3.25 per dozen. It is well flavoured and generally eaten straight from the shell. Cupped oysters, however, are apparently less well flavoured and do not command such a high price. In America, species such as *C. gigas* and *C. virginica* are shucked (i.e., the meats are removed from the shells) and processed before they are marketed.

The exploitation, management and study of *O. edulis* have a long history which will be outlined briefly below in an attempt to put current and contemporary work in perspective.

The family Ostreidae, which includes both *Ostrea* and *Crassostrea* first appeared for certain in upper Triassic deposits (i.e., approximately 200 million years ago) and became abundant in the Jurassic and Cretaceous periods (Yonge, 1960). Man's first knowledge of oysters comes from the presence of shells in prehistoric kitchen middens in coastal areas all over the world. Discarded shells of *O. edulis* have been discovered in abundance in Norway, Brittany, Scotland and Ireland.

Aristotle was one of the first to write about oysters in his "Historia Animalium" and Pliny in the first century B.C. also discussed oysters in his book "Natural History" but added little to scientific knowledge (Yonge, 1960). It was during the time of Pliny (ca B.C. 95), however, that oyster culture was first attempted in the west by Sergius Orata who established artificial oyster beds at Baiae (Philpots, 1890).

The Romans were very impressed with British oysters which they collected mostly from the Kent coast. However, after they left Britain few records of oyster exploitation or cultivation appeared until the Renaissance when there was an upsurege of interest in oyster husbandry.

By the mid-seventeenth century references to black sick and white sick oysters (see Chapter IV) were appearing in the literature suggesting that oysters were then known to produce sexually. Then, in 1672, the first detailed account of the anatomy of O. edulis was given by Thomas Willis in his book "De Anima Brutorum" (Souls of Brutes). Oyster larvae were first observed in the Adriatic and described in 1689 by J. Brach in "De Ovis Ostreorum" (Yonge, 1960). Further important discoveries were made in the early nineteenth century but it was not until the early part of the twentieth century that great advances were made in oyster biology.

The intense interest shown in oyster biology during the first half of the twentieth century was closely linked with the serious decline in oyster production which started in Europe about one hundred years earlier. In France the decline was so sudden that government intervention was necessary to revive the industry and early measures were taken to rebuild the oyster stocks by Professor P. Coste. Furthermore, public oyster grounds were withdrawn from the free fishery which then existed and leased by the state to individual oyster farmers - a situation which still prevails today. Holland also placed public fisheries in private hands and with the aid of stringent fishery regulations and the provision of suitable cultch (e.g., shells of oysters, mussels, etc.) to collect spat soon created a highly productive oyster industry.

In the United Kingdom (which included Ireland at that time) the decline in oyster production was slower and somewhat insidious. Firm steps to reverse the downward trend were not taken and even today, after fifty years of intensive research, landings in Britain and Ireland (Table 3) are only a fraction of those of 1870. In that year, when oysters were purchased regularly by the poor, nearly 500 million oysters were sold at Billingsgate alone.

Bearing in mind the economic importance of oysters in Europe during the last century it is not surprising to find that much research effort was directed towards an understanding of the biology of _O. edulis_ and the development of new cultivation techniques. Most of the investigations were conducted in Holland, France and Britain, but the fundamental research of Spärck and his colleagues in Denmark should not go without mention (Spärck, 1924; 1929).

The Dutch biologists Havinga and Korringa contributed greatly to the present knowledge of _O. edulis_ particularly in the fields of growth, reproduction and the biology of parasites, predators and competitors affecting the species in Holland. Korringa developed much of the scientific management technique which formed the foundation of the efficient and valuable Dutch oyster industry. Unfortunately his effort has been set at nought because most of the Dutch oyster beds have now been reclaimed or flooded with fresh water to increase Holland's land surface and water supply. However, his extensive works are still a valuable guide in the study and development of new oyster fisheries.

TABLE 3.

LANDINGS AND VALUES OF FLAT OYSTERS *(O. EDULIS)*
IN IRELAND AND THE UNITED KINGDOM (ENGLAND AND WALES)
FROM 1919 TO 1971

YEAR	IRELAND			UNITED KINGDOM		
	Number	Value (£)	Value per oyster (p)	Number	Value (£)	Value per oyster (p)
1919				31,111,000	200,740	0.64
1920				36,439,000	254,540	0.70
1921				31,027,000	207,909	0.67
1922				26,666,000	177,285	0.66
1923				18,102,000	151,618	0.84
1924				16,720,000	146,847	0.88
1925				16,740,000	105,606	0.63
1926	1,622,344	7,619	0.47	15,857,000	154,757	0.98
1927	1,361,371	6,027	0.44	9,712,000	101,480	1.05
1928	2,280,022	10,216	0.45	8,057,000	87,044	1.08
1929	645,790	4,847	0.75	7,377,000	59,647	0.81
1930	1,888,038	8,712	0.46	6,937,000	58,080	0.83
1931	1,315,747	5,773	0.44	7,044,000	61,689	0.88
1932	2,202,160	9,715	0.44	10,740,000	88,522	0.82
1933	1,196,148	4,446	0.37	10,710,000	96,255	0.90
1934	1,047,191	5,048	0.48	12,008,000	107,238	0.90
1935	366,876	1,925	0.53	15,799,000	140,002	0.90
1936	319,501	2,087	0.65	19,187,000	176,033	0.92
1937	293,467	1,847	0.63	16,582,000	142,152	0.86
1938	204,467	1,479	0.72	16,363,000	132,938	0.81
1939	460,231	2,869	0.62	12,143,000	100,767	0.83
1940	765,284	4,909	0.64	8,858,000	73,635	0.83
1941	456,352	3,727	0.82	9,800,000	94,313	0.96
1942	578,080	5,917	1.02	5,539,000	74,610	1.35
1943	760,007	8,494	1.10	4,946,000	67,217	1.36
1944	1,390,256	17,724	1.30	4,535,000	64,868	1.43
1945	1,516,651	17,739	1.20	5,651,000	107,665	1.91
1946	1,303,790	17,663	1.40	7,850,000	135,438	1.73
1947	1,007,094	12,042	1.20	6,674,000	110,398	1.65
1948	1,051,711	12,220	1.20	8,948,000	136,484	1.53
1949	630,631	7,380	1.20	8,002,000	151,469	1.89
1950	454,057	4,484	1.00	8,952,000	168,438	1.88

Sources: Sea Fisheries Statistical Tables. H.M.S.O., London, and the Sea and Inland Fisheries Annual Report of the Fisheries Division of the Department of Agriculture and Fisheries, Dublin.

Table 3. Continued (ii)

YEAR	IRELAND			UNITED KINGDOM		
	Number	Value (£)	Value per oyster(p)	Number	Value (£)	Value per oyster(p)
1951	252,537	3,232	1.27	8,856,000	164,842	1.86
1952	420,476	4,761	1.13	7,617,000	140,467	1.84
1953	639,841	6,489	1.01	8,374,000	162,160	1.94
1954	403,115	5,361	1.33	7,809,000	149,159	1.91
1955	267,611	3,100	1.16	7,516,000	142,138	1.89
1956	254,238	2,688	1.06	7,280,000	134,471	1.85
1957	537,760	5,389	1.00	6,980,000	135,332	1.94
1958	611,835	8,857	1.45	6,201,000	118,405	1.91
1959	639,223	9,469	1.48	5,788,000	114,603	1.98
1960	1,204,248	11,777	0.98	5,514,000	110,926	2.01
1961	1,404,012	14,398	1.03	4,628,000	91,798	1.98
1962	1,750,270	22,360	1.28	4,059,000	89,084	2.20
1963	1,328,707	22,445	1.69	2,947,000	56,466	1.91
1964	1,228,213	26,558	2.17	3,171,000	74,876	2.36
1965	1,465,179	31,084	2.12	4,000,000	80,000	2.00
1966	1,387,201	29,871	2.15	4,000,000	88,000	2.20
1967	1,371,825	29,852	2.18	4,000,000	98,000	2.45
1968	1,540,122	34,103	2.21	4,000,000	139,000	3.48
1969	2,650,754	75,802	2.86	4,000,000	146,000	3.65
1970	1,619,381	51,205	3.16	4,000,000	180,000	4.50
1971	2,939,620	74,835	2.55			

Sources: Sea Fisheries Statistical Tables. H.M.S.O., London, and the Sea and Inland Fisheries Annual Report of the Fisheries Division of the Department of Agriculture and Fisheries, Dublin.

Marteil did much to improve the French oyster industry be developing spat collection on a firm scientific basis at Morbihan (Marteil, 1960). This area became a major spat producing centre, supplying much of the seed required by oyster farmers in France and abroad.

In Britain, Orton undertook much of the basic research on the biology and cultivation of oysters and his Buckland Lecture (1935), "Oyster Biology and Oyster Culture" (Orton, 1937) is still unsurpassed in many respects. His work at the Marine Biological Association's Laboratory at Plymouth was continued by Cole at the Ministry of Agriculture and Fisheries experimental stations at Burnham-on-Crouch, Essex, and Conway, North Wales, where more emphasis was placed on the artificial rearing and behaviour of oyster larvae (e.g., Cole, 1939; 1956).

In Scotland, Millar attempted to revive some of the once productive oyster fisheries of the west coast which he surveyed in detail and described in a Department of Agriculture and Fisheries for Scotland report (Millar, 1961).

These applied investigations have been complemented by the more academic approach of Professor C.M. Yonge. He devoted much of his research to the evolution and physiology of oysters but he has compiled material covering nearly the whole spectrum of the oyster world in his monograph "Oysters" (Yonge, 1960) which has done much to revitalise interest in the subject.

Little basic research, beyond general oyster bed surveys and trial transplants, has been undertaken in Ireland since E.W. L. Holt of the Department of Agriculture and

Technical Instruction for Ireland carried out a series of surveys and experiments on east coast and west coast fisheries at the turn of the century (Holt, 1903). However, a new initiative is being taken and the current research programmes will be described later in this thesis.

In Europe the emphasis in research has moved from basic biology to the study of management techniques, hatchery rearing of oyster seed and pest control. The reduction in the number of areas suitable for extensive sea-bed cultivation has made urgent the need to develop new intensive cultivation techniques. New materials are being utilized to improve the holding and handling of oysters on the sea bed and in suspension from rafts or permanent structures. Attempts are also being made to overcome the fluctuations in natural seed production by the artificial rearing of seed oysters in hatcheries (Walne, 1956a). As yet no reliable and economic system has been devised to produce _O. edulis_ seed in sufficient quantities to supply the potential market. However, _C. gigas_ spat can be reared with less difficulty and the market for this species, which generally grows faster than _O. edulis_, is expanding (see Chapter VII).

Oyster pests and diseases have also been studied intensively during the last fifty years in attempts to avert the total destruction of large European fisheries by previously unidentified disease organisms and alien predators (e.g., Korringa, 1951a). Fortunately such studies have been unnecessary in Ireland where the oyster stocks have escaped major epidemics and where no alien predators have been successfully introduced. Furthermore, Irish waters have remained relatively free from pollution in contrast to other coastal areas in Europe where the livelihoods of many oyster growers are seriously threatened by the increasing volumes of industrial and domestic effluents being discharged over their oyster grounds (e.g., Brittany, Madec, pers. comm.).

Early in the 1960's the Irish Government recognised the potential value of the clean water, indented coastline and indigenous oyster stocks of the west coast for the development of an oyster industry which would benefit both local and national economies. In 1964, at the request of the Government, an American team of fisheries experts conducted a survey of Irish sea fisheries resources. In their report (1964) they recommended the development of the oyster industry on the basis of sound biological knowledge. In 1967, the Resource Development section of An Bord Iascaigh Mhara - the Irish Sea Fisheries Board, abbreviated to B.I.M. throughout the thesis - published its first report on a survey of the Clarinbridge Public Oyster Fishery (Edwards et al, 1967). Subsequently a programme of research and development was introduced in which this author was closely involved. The purpose of this programme was to gather biological information which could be used as a basis for the management and development of this locally valuable resource and to provide information for the private oyster farmers in Galway Bay and elsewhere in Ireland.

This thesis describes the studies made by the author on behalf of B.I.M., mainly at the Clarinbridge Public Oyster Fishery, since the summer of 1968. Field work was undertaken during the summers of 1968 and 1969 and then continuously from February 1970 until August 1972. The study involved a close examination of the Clarinbridge Fishery with comparative observations on private fisheries in Galway Bay and elsewhere. The biological investigations were concerned mainly with the study of growth and reproduction of oysters but information was also collected on associated fauna, predators and competitors. Environmental factors - water temperatures and salinity - were monitored throughout the investigations and weather data, recorded at University College, Galway, are also presented. Reference is made to studies on *Ostrea edulis* in Britain, France and Holland and information is also drawn from American sources where this is relevant.

Little comparative information is available on Irish oyster fisheries. Browne (1904) and Went (1962) present valuable historical evidence of Irish oysters and their exploitation, but since Ireland became independent little research has been directed towards the development of Irish oyster fisheries. Currently the Fisheries Division of the Department of Agriculture and Fisheries is investigating the public oyster fishery at Tralee but no extensive published results are yet available. This thesis, therefore, presents the first comprehensive account of modern Irish oyster fisheries.

CHAPTER II

OYSTERS IN IRELAND

II. OYSTERS IN IRELAND

Ostrea edulis is a native of Irish waters and its existence has been known from prehistoric times when it was gathered and eaten by people dwelling near the shore. The empty shells were deposited in kitchen middens or shell mounds, many of which have survived to the present day (e.g., at Galway Bay, Philpots, 1890; at Cork Harbour, Ó Ríordáin, 1965) as evidence of formerly extensive Irish oyster stocks. In addition, strata composed of old, often hinged, oyster shells which have been discovered in cliffs of Pleistocene material (e.g., at Galway Bay and Sligo Bay) provide further evidence of the existence of ancient oyster beds on the west coast of Ireland (Keary, pers. comm.).

Oysters probably existed in most suitable bays around Ireland and whilst they were subject only to local exploitation the stocks were satisfactorily maintained (Went, 1962). However, improved transport facilities in the nineteenth century led to increased commerce and this encouraged the exploitation of Irish oyster stocks for distant markets with the result that many oyster beds were drastically overfished, some to extinction.

Today there are only two public oyster fisheries remaining in Ireland which can provide local fishermen with worthwhile catches -- the Clarinbridge fishery in County Galway and the Tralee fishery in County Kerry. Furthermore, the number of private commercial fisheries and oyster layings is only a fraction of that in existence seventy years ago when most suitable areas around the coast were utilized to some degree for oyster production.

Thus, the total production of Irish oysters is considerably less now than it was at the turn of the century and even then, according to Holt (1903) "the oyster industry, once of great importance in this country, is at present in a very depressed condition." The reasons he gave for this slump were "in part the low state of the market which renders it difficult to dispose of the coarser grades of natural oysters at a price remunerative to the dredgers; and partly the shortage of local supplies of seed oysters suitable for relaying on fattening beds." Whilst the marketing situation has been somewhat ameliorated in recent years the shortage of oyster seed is still a great hindrance to the development of the Irish oyster industry.

In other respects, too, the industry has changed little since the early years of this century. There have been no major changes in legislation relating to oyster fisheries and few technical innovations to increase production. The introduction of powered boats for dredging has made oyster fishing easier but has raised the overall catch only marginally (see later).

The recent and continuing expansion of the oyster industry has occurred largely as a result of the increased foreign demand for Irish oysters which developed after the severe winter of 1962-63 when large stocks in Britain and on the Continent were destroyed during the prolonged freezing conditions and subsequent thaw (Duggan, pers. comm.).

PART A. THE DISTRIBUTION AND HISTORY OF OYSTERS IN IRELAND

The distribution of oyster beds in Ireland in 1903 is shown in Map 1. At this time there were, according to Browne (1904), 24 public or natural oyster fisheries, 8 chartered fisheries (see later), 62 licensed fisheries and 7 unlicensed fisheries. Map 2. shows the present distribution of commercial oyster beds with additional indications of private areas undergoing, or suitable for development.

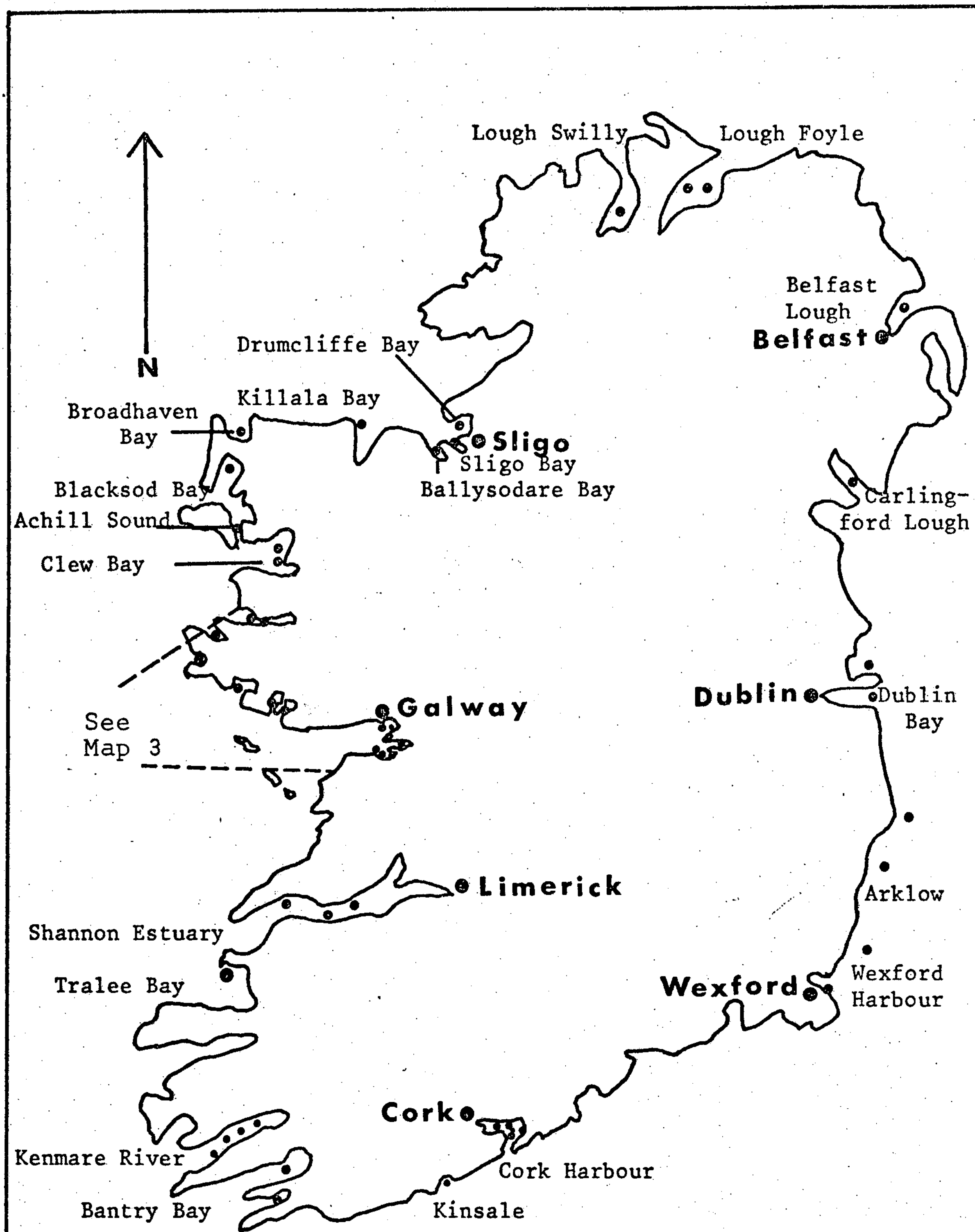
Many records of oysters appear in Irish literature but very few provide insight into the state of the industry or of oyster husbandry in the country during any particular period. However, Went (1962) has summarised much of the historical information that is available and it is from his paper and the Government report of Dr. T.J. Browne (1904), Medical Inspector of the Local Government Board of Ireland, that much of the material in the following résumé is drawn.

East Coast Fisheries

Several important oyster grounds once existed on the east coast of Ireland. However, landings from these fisheries declined during the first half of this century (Table 4) and none has been exploited commercially since about 1945.

MAP 1. OYSTER BEDS IN IRELAND IN 1903

(After Browne, 1904)



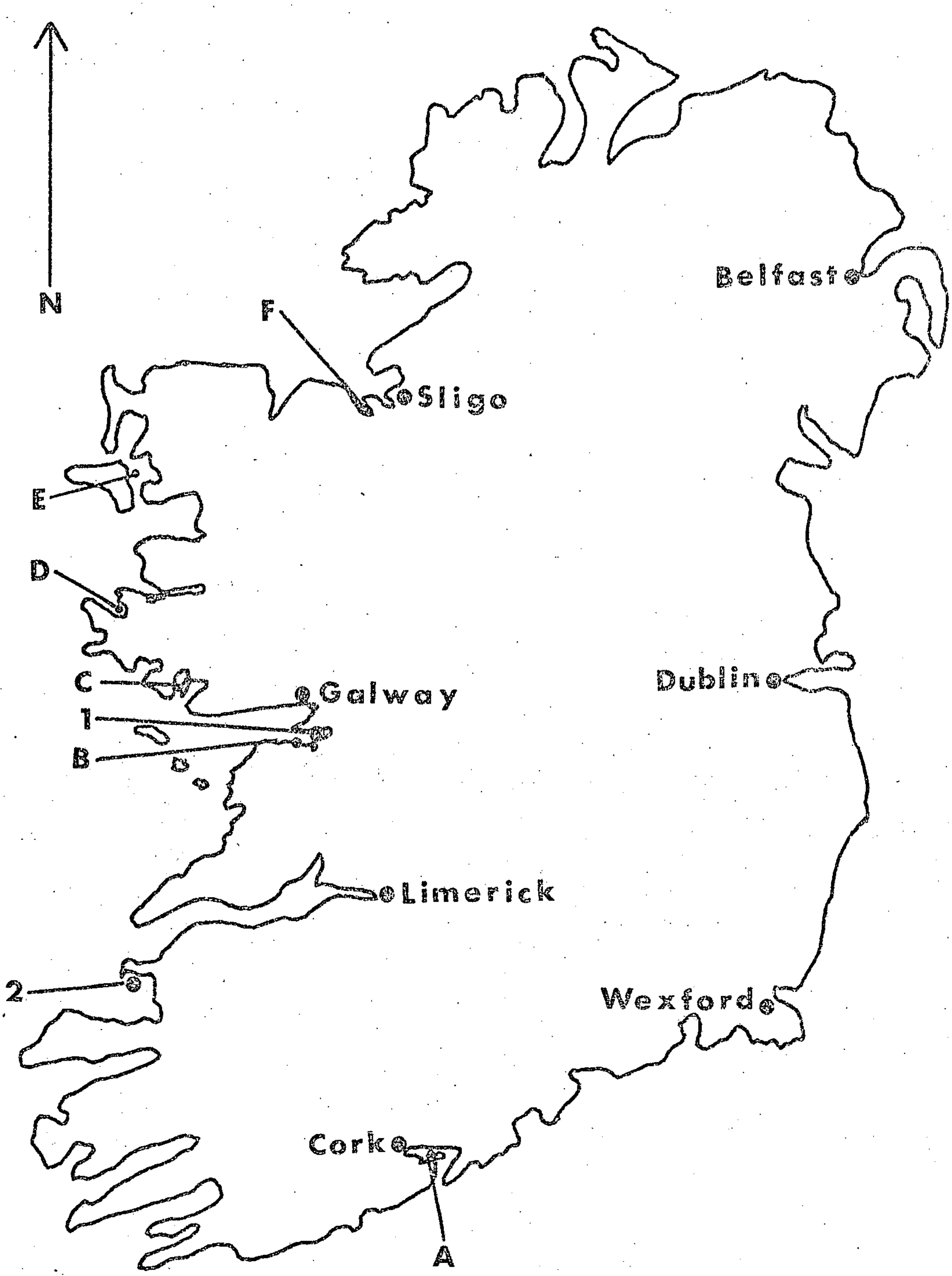
A most notable disappearance was that of the natural oyster beds in Carlingford Lough and the estuary of the Newry River which, according to Philpots (1890) and Holt & Hillas (1905), produced some of the best Irish native oysters. Here during the 1902-03 (November 1st-January 15th) fishing season, 80 boats, each crewed by 3 men, landed 1,500,000 oysters all of which had apparently resulted from a natural spat settlement (Browne, 1904). Went, however, noted that the beds had been fished out during the years prior to 1874 and it is, therefore difficult to ascertain whether the large stocks present in 1903 had been produced by an indigenous population or by foreign oysters which had been planted on private layings nearby. However, the fishery declined again after that productivity period and today oysters no longer occur in commercial quantities in the area, although trials conducted by the author (Whilde, 1971b) showed that Carlingford Lough will still support fast-growing oysters, superior in quality to those grown on the west coast.

Other east coast oyster beds were located at the mouth of the River Liffey, in Dublin Bay and off the coasts of Wicklow and Wexford. The latter oyster grounds, which occur in deeper water than others in Ireland, were highly productive between about 1800 and 1870 (Philpots, 1890) but subsequently landings declined (Holt, 1901) and commercial exploitation eventually ceased.

South Coast Fisheries

Cork Harbour was once the major oyster producing

MAP 2. OYSTER BEDS IN IRELAND IN 1972



KEY

1-2 Public Oyster Beds

1 Clarinbridge 2 Tralee Bay

A-F Private Oyster Beds

A. Cork Harbour D. Ballinakill Harbour

B. Galway Bay E. Achill Sound

C. Kilkieran Bay F. Ballysodare Bay

area on the south coast. It supported several flourishing fisheries until the turn of the century when, according to Browne, production was declining. Currently several areas of the Harbour are undergoing private redevelopment.

West Coast Fisheries

Tralee Bay Oyster Fishery

Historically this was one of the most productive public oyster fisheries in Ireland. For instance, during the 1902-03 fishing season (November 1st-March 10th) 20 boats, each crewed by 3 men, landed 3 million oysters which were bought by local dealers for 1s.6d (7½p) per long hundred (126 ; see later). At that time only oysters exceeding 2½ inches in diameter could be removed legally from the bed for sale (Holt and Hillas, 1905) but the regulation was not being enforced and the majority of oysters landed were unsuitable for consumption and had to be relaid on private oyster grounds in Cork, Sligo, Clifden and Galway Bay (Browne, 1904).

The Shannon Estuary

This estuary once supported commercially important oyster stocks but by the turn of the century the public beds were yielding few oysters and many of the private layings had become derelict. Today, only the occasional oyster may be caught, although oyster shells are still abundant on some parts of the shore. However, several areas are still held under licence and interest has been

TABLE 4. THE LANDINGS AND VALUES OF OYSTERS IN VARIOUS PARTS OF IRELAND FROM 1926 TO 1971

YEAR	EAST COAST		SOUTH COAST		WEST COAST		NORTH COAST			
	Omeath-Carnsore Pt.		Carnsore Pt.-Loop Hd.		Loop Hd.-Erris Hd.		Erris Hd.-Moville		Total	Total
	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
1926	960,000	3,840	282,360	1,374	256,264	1,374	123,720	1,031	1,622,344	7,619
1927	984,000	3,280	215,676	1,476	143,000	1,091	18,695	180	1,361,371	6,027
1928	1,848,000	6,444	237,528	2,051	192,194	1,695	2,300	26	2,280,022	10,216
1929	101,050	409	453,100	3,531	70,840	698	20,800	209	645,790	4,847
1930	1,600,000	6,420	173,099	1,467	40,630	274	1,700	25	1,888,038	8,712
1931	1,200,000	4,800	55,995	540	59,320	429	432	4	1,315,747	5,773
1932	2,000,000	8,000	103,555	958	96,877	743	1,728	14	2,202,160	9,715
1933	1,011,600	2,798	134,246	1,199	50,302	449	--	--	1,196,148	4,446
1934	940,080	3,917	35,995	304	67,756	799	3,360	28	1,047,191	5,048
1935	269,000	922	58,880	648	36,596	335	2,400	20	366,876	1,925
1936	129,586	390	104,580	929	81,935	727	3,400	41	319,501	2,087
1937	90,009	226	48,468	390	153,790	1,216	1,200	15	293,467	1,847
1938	36,440	107	45,028	376	122,999	996	--	--	204,467	1,479
1939	76,060	637	67,893	564	317,928	1,967	350	2	460,231	2,869
1940	327,300	2,319	19,312	209	415,312	2,339	3,360	42	765,284	4,909
1941	49,100	321	40,925	349	361,959	3,004	4,368	53	456,352	3,727
1942	49,400	575	87,526	874	427,882	4,329	13,272	139	578,080	5,917
1943	9,900	139	65,256	748	653,651	7,217	31,200	390	760,007	8,494
1944	18,800	371	52,346	507	1,292,020	16,523	27,090	323	1,390,256	17,724
1945	50,000	500	49,013	490	1,386,642	16,380	30,996	369	1,516,651	17,739
1946	-	-	26,946	256	1,261,976	17,218	14,868	189	1,303,790	17,663
1947	-	-	9,812	72	970,066	11,646	27,216	324	1,007,094	12,042
1948	-	-	9,576	91	1,018,195	11,844	23,940	285	1,051,711	12,220
1949	-	-	44,486	421	559,685	6,696	26,460	263	630,631	7,380
1950	-	-	45,219	638	354,118	3,704	54,720	142	454,057	4,484

Source: Sea and Inland Fisheries Annual Reports, Department of Lands, Fisheries Division, Dublin.

Table 4 Continued (ii)

YEAR	EAST COAST		SOUTH COAST		WEST COAST		NORTH COAST			
	Omeath-Carnsore Pt.		Carnsore Pt.-Loop Hd.		Loop Hd.-Erris Hd.		Erris Hd.-Moville		Total	Total
	No.	Value	No.	Value	No.	Value	No.	Value		
1951	-	-	8,160	174	227,493	2,857	16,884	201	252,537	3,232
1952	-	-	35,010	285	370,346	4,296	15,120	180	420,476	4,761
1953	-	-	61,944	544	562,281	5,771	15,616	174	639,841	6,489
1954	-	-	148,178	2,348	241,959	2,858	12,978	155	403,115	5,361
1955	-	-	53,770	543	213,841	2,557	-	-	267,611	3,100
1956	-	-	35,100	365	219,138	2,323	-	-	254,238	2,688
1957	-	-	56,574	561	481,186	4,823	-	-	537,760	5,389
1958	-	-	44,100	472	567,735	8,385	-	-	611,835	8,857
1959	-	-	29,600	363	609,623	9,106	-	-	639,223	9,469
1960	-	-	693,000	5,500	511,248	6,277	-	-	1,204,248	11,777
1961	-	-	-	-	-	-	-	-	1,404,012	14,398
1962	-	-	-	-	-	-	-	-	1,750,270	22,360
1963	-	-	-	-	-	-	-	-	1,328,707	22,445
1964	-	-	-	-	-	-	-	-	1,228,213	26,558
1965	-	-	-	-	-	-	-	-	1,465,179	31,084
1966	-	-	-	-	-	-	-	-	1,387,201	29,871
1967	-	-	-	-	-	-	-	-	1,371,825	29,852
1968	-	-	-	-	-	-	-	-	1,540,122	34,103
1969	-	-	-	-	-	-	-	-	2,650,754	75,802
1970	-	-	-	-	-	-	-	-	1,619,381	51,205

Source: Sea and Inland Fisheries Annual Reports, Department of Lands, Fisheries Division, Dublin.

shown in the redevelopment of some of them using intensive cultivation techniques(Whilde, 1970a).

The Mayo Coast

On the Mayo coast natural oyster beds existed in Clew Bay, Achill Sound, Blacksod Bay and Broadhaven Bay but by 1900 these areas were fished out. Oysters still occur in Clew Bay, but the re-establishment of an oyster fishery there has not been encouraged by the Department of Agriculture because Dutch shell disease is known to have occurred in the area (Duggan, pers. comm.). (This disease, which will be referred to again in a later section, is caused by a fungus which not only attacks live oysters but can also exist in the dead shells of other species such as cockles). High quality oysters still occur in small numbers on the eastern shores of Achill Island and small pockets of oysters may be found on the shores of Blacksod and Broadhaven Bays (Whilde, 1970b).

The Sligo Coast

Extensive oyster cultivation was once practised on the coast of County Sligo. However, most of the fisheries and layings, such as those in Sligo Bay and Drumcliffe Bay, have been allowed to fall into dereliction and only one private fishery, in Ballysodare Bay, is worked today.

The Coast of Donegal and Northern Ireland

Small oyster populations once existed in the bays and estuaries of Donegal and on the coast of Northern Ireland but they have not been exploited commercially for many years. Currently, however, the Ministry of Agriculture and Fisheries

Northern Ireland is attempting to develop an oyster industry based on a number of small productive fisheries which will be set up and managed by properly trained personnel (Parsons, pers. comm.).

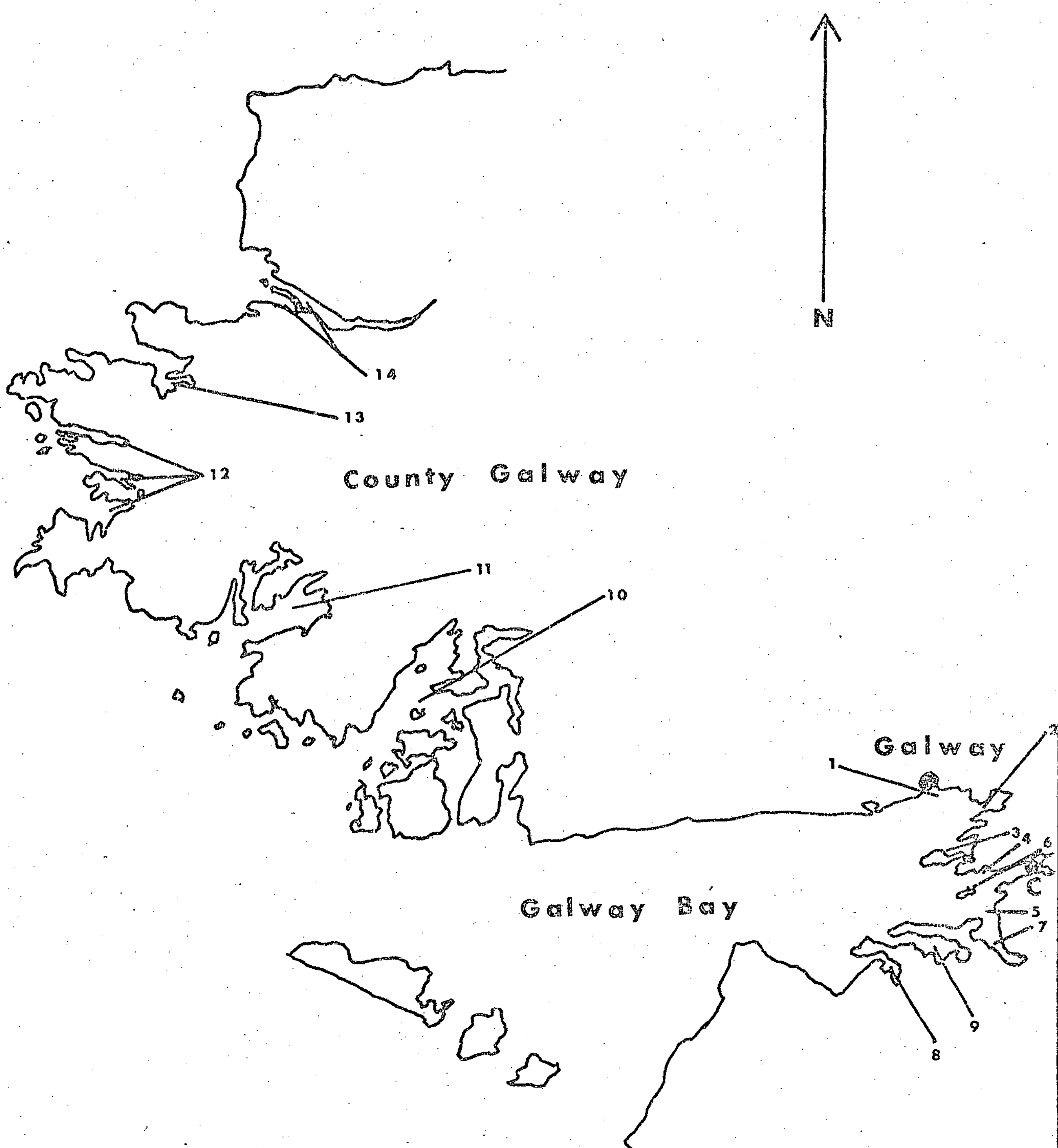
The oyster fisheries of Galway Bay and County Galway

Galway Bay has a long and famous tradition of oysters and their popularity can be traced back nearly four centuries. In 1589, Sir George Carew in a despatch to Sir William Fitzwilliam commanded a Galway victualler "to bring us beer and bread and an oyster dredge or two in hope to scrape somewhat out of the sea." Nearly 100 years later Roderick O'Flaherty is reported to have written that Galway Bay was well stocked with fish " and no less liberal with shellfish, including oysters" (Went, 1962).

The most important fisheries in Galway Bay appear to have existed only on the eastern and southern shores although several productive oyster beds flanked the mouth of the bay on the north shore (Map 3). Oysters from the Burren, on the south shore, were particularly renowned and during the reign of Charles II they were said to be far superior to the famous Colchester oysters which were, and still are, regarded as the finest oysters in Britain if not in the whole of Europe.

At the beginning of the nineteenth century there were reports that the oysters beds near Galway were being fished out and required restocking with oysters from the south shore of the bay. However, by 1836, even the Burren oysters were becoming scarce and it became necessary to

MAP 3. OYSTER BEDS OF GALWAY BAY AND COUNTY GALWAY



KEY C Clarinbridge Public Oyster Fishery

1. Rinmore Point
2. Oranmore Bay
3. Ardfry
4. Ballynacourty
5. St. George
6. Island Eddy
7. Crossooha
8. Muckinish Bay
9. Aughinish Bay
10. Kilkieran Bay
11. Cashel Bay
12. Clifden Bay, Ardbear Bay, Mannin Bay
13. Ballinakill Harbour
14. Killary Harbour

relay oysters from both Galway and Mayo on these beds. Holt & Hillas (1905) also reported that in 1905 the oyster beds in the Clarinbridge area were being too heavily fished and that they would no longer be able to support economic fisheries if overexploitation was not discontinued.

Browne (1904), in his detailed survey of Irish oyster beds devoted much attention to both the public and private fisheries of Galway Bay and the west coast of County Galway. The historical observations presented in the following brief descriptions of these oyster fisheries are abstracted largely from his report. The remaining comments are drawn mostly from the author's unpublished observations in the area.

The location of the oyster beds described below are given on Map 3.

(1) A small bed off Rinmore Point at the mouth of Galway Bay docks. Large oysters can still be found here but they are heavily polluted by effluent from Galway City and must be purified before sale (Power, pers. comm.).

(2) In 1903 a natural oyster bed occupied the whole of Oranmore Bay where there was said to be a considerable spatfall each season. Oysters are still fished there, usually after the Clarinbridge fishing season has finished. However, they are reported to be heavily contaminated (cf. Chapter VI) by Galway sewage effluent and must be purified before they can be sold (Power, pers. comm.). Casual observations suggest that the oyster population is smaller than in 1903 although it is still sufficient to produce a

regular spatfall. Oranmore Bay oysters are characteristically thin, fast growing and smooth shelled, being typical of oysters growing on a predominantly sandy bottom which is scoured by strong currents.

(3) The Ardfry oyster grounds have been cultivated intermittently since the turn of the century and it was on these grounds that Holt and his colleagues carried out many of their experiments from 1903 onwards. Although at present they are untended, good quality oysters are still collected from the grounds at low spring tides (Whilde, in press b).

(4) Ballynacourty oyster bed lies to the west of the Clarinbridge fishery and between Mweenish Island and the mainland. It has been derelict for some time and the sea bed, which is composed of mud, is difficult to cultivate (Whilde, in press, a).

(5) The St. George Oyster Bed, a chartered fishery, covers an area running approximately from Mweenisharan to Pollagh Quay. The fishery is virtually derelict and has been overrun by starfish (*Asterias rubens*). However, it has considerable potential for development as a result of the heavy natural spat settlements which occur in the area and for this reason it will be mentioned again in a later section.

(6) The Island Eddy oyster bed, situated on the north, east and south shores of the island, was once privately operated. Today, there is apparently no legal

claimant for the fishery and local fishermen occasionally dredge the grounds when the Clarinbridge season is over.

(7) An oyster fishery called Crossooha (current spelling), Crushena (Browne) or Crusrua (Holt) still persists in Kinvara Bay. Browne considered it to be a public fishery which the people of the nearby village of Crossooha looked upon as their private property. However, it has since been confirmed that thirteen tenants of the village have legal rights to the oyster bed, dating back to 1896, along with rights to cut seaweed in the area and, apparently, they also pay rent and rates for the fishery. The tenants guard their fishery jealously and refused to permit the author to survey the oyster bed.

Apparently only a few of the tenants actually fish the bed these days, but the catches are pooled and divided amongst the tenants according to the size of their individual shares. At the beginning of the century the fishery yielded about 100,000 good quality oysters annually and even today it provides worthwhile fishing; approximately 30,000 oysters were landed in 1971 (Moran, pers. comm.).

(8) Several private oyster layings were planted in Muckinish Bay on the southside of Galway Bay at the beginning of the century. Subsequently these fell into disuse, but in recent times renewed interest has been shown in the area (Whilde, 1970c), which was once the home of the famous Pouldoddy or Redbank oysters (Stone, 1906).

(9) Philpots (1890) mentions that oysters from

Kilkieran and Rosmuck Bays used to be relaid for fattening in Aughinish Bay, which is situated between Kinvara and Muckinish Bay. However, Browne (1904) does not mention an oyster fishery in the area and it would appear that the fishery fell derelict and remained in that condition until the middle of the present century when oysters were again relaid in the Bay. The fishery is now the most productive private enterprise in Ireland with considerable potential for expansion. The oysters grown here are of good quality, both in terms of meat content and appearance and natural spat settlement ensures at least partial replenishment of the stocks annually (Hugman, pers. comm.).

(10) Kilkieran Bay, which is situated near the mouth of Galway Bay, harbours a large natural oyster bed. It has a history of private ownership, during which it produced large quantities of seed oysters (e.g., 200,000 in 1903). In recent years, however, it seems that the grounds have been fished publicly and in such a manner as to deplete the stocks. The oysters are generally of inferior quality as a result of the poor ground on which they occur and the large amount of fresh water which enters the bay (Whilde, 1969 and in press c). Traditionally oysters were transplanted in the neighbouring Cashel and Bertraghboy Bays for fattening before sale.

(11) Cashel Bay and Bertraghboy Bay are no longer used for fattening Kilkieran Bay oysters but small stocks of oysters still exist along their shores near low water mark (Whilde, in press b).

(12) Clifden Bay, Ardbear Bay and Mannin Bay were all used for laying oysters in the past but they are no longer extensively used for this purpose.

(13) Ballinakill Harbour was the site of costly oyster cultivation schemes in the past, but these did not have lasting success. One area of the Harbour is still held under licence and is currently undergoing private redevelopment (Whilde, in press c).

(14) Several layings and public oyster fisheries once existed in Killary Harbour and Little Killary Bay (Stone, 1906) but these are no longer worked, although small populations of oysters may still be found at low water.

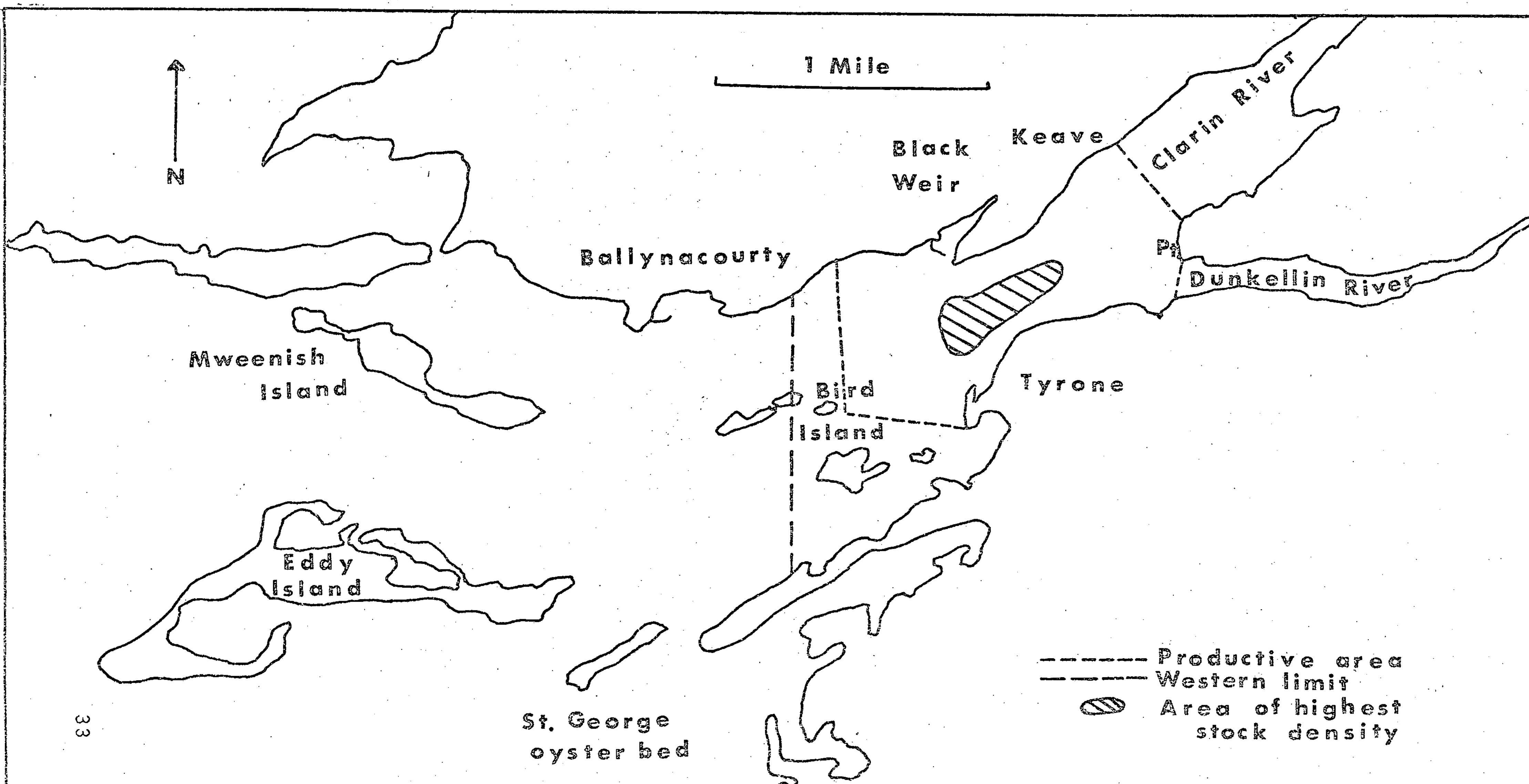
It is interesting to note, in light of the excellent settlement and growth of mussels in the area reported by Murray (1971), that several oyster layings "were overrun by mussels, and so rendered valueless," in the latter part of the nineteenth century (Philpots, 1890).

<u>The Clarinbridge Public Oyster Fishery</u> (Map 4)

This fishery, known as the Stradbally Public Oyster Fishery in 1903, is a natural oyster bed situated in the estuary of the Clarinbridge and Dunkellin Rivers at the eastern end of Galway Bay. The oyster grounds are located between Kilcolgan Point in the east and Bird Island on the west. In 1903 it was described as one of the most prolific oyster beds in Ireland and second only to the public oyster bed at Tralee as a spatting ground (Browne, 1904).

MAP 4.

THE CLARINBRIDGE PUBLIC OYSTER FISHERY



Fishing at Clarinbridge was, and still is, permitted only during the month of December, apparently according to the wishes of the fishermen themselves but now according to a local bye law. However, when Browne was carrying out his survey the bed was dredged only for the first ten days of the month, when 150-200 boats landed about 300,000 oysters. In 1905 Holt & Hillas (1905) suggested that the grounds were being overfished and this is not surprising as Browne points out that many of the oysters removed from the fishery were only 1½ to 2½ inches in diameter in spite of the legal minimum size of 3 inches.

The Clarinbridge fishery was protected in the past by baliffs selected and paid (usually 100 oysters from each boat) by the fishermen themselves. Unfortunately this system broke down in the mid 1950s because some fishermen would not meet their obligations. As a consequence, it became necessary for the Galway Board of Fishery Conservators to supervise the dredging for one year, their expenses being met by a Government grant. In 1959 a licence duty was imposed on all boats used for the capture of oysters and levied by the Board of Conservators to assist them in the supervision of the fishery (Went, 1962). Currently two or three baliffs patrol the fishery daily during December examining catches and the fishermen's oyster layings on the shore.

Today the basic management of the fishery is conducted by the Clarinbridge Oyster Development Committee who, in conjunction with the Resource Development Section of B.I.M. are introducing cultivation techniques to improve the quality and increase the quantity of oysters landed at the fishery (Whilde, in press, c).

PART B. THE PRESENT-DAY FISHERY

Landings, values and fishing effort

Oysters landings in Ireland have fluctuated considerably since 1926 (Table 3) but during the last decade they have steadied at around 1.5 millions per annum. Values, however, have risen sharply since 1960, although the annual contribution of oysters as a proportion of total Irish shellfish landings has not varied greatly, being on average, about 6 per cent (Table 5). This suggests that oyster production is holding its own in the expanding Irish shellfish industry.

Table 4 gives a breakdown of oyster landings by coastal areas from 1926 to 1971. It shows how production, whilst not fluctuating greatly in total, has shifted from the east coast to the west coast and finally concentrated at Tralee and Clarinbridge during the last decade.

The average prices of oysters landed in Ireland and the United Kingdom, represented as the cost of a single oyster, in ten year periods since 1926, are presented in Table 6. It will be noted that oyster prices rose steadily between 1926 and 1965 but increased dramatically in the latter part of the 1960s in both countries. The table also shows that United Kingdom oysters have always commanded a higher first sale price than Irish oysters.

TABLE 5. VALUES OF SHELLFISH LANDED IN IRELAND FROM 1960 TO 1971

YEAR	VALUES (£)										%
	Oysters	Mussels	Periwinkles	Escallops	Lobsters	Crawfish	Crabs	Dublin Bay Prawns	Other Shellfish	Total	CONTRI- BUTION OF OYSTERS
1960	11,777	16,548	50,559	7,030	130,985	93,254	751	28,437	284	339,625	3.5
1961	14,398	7,187	56,892	5,390	101,615	58,372	1,490	31,559	783	277,686	5.2
1962	22,360	3,086	55,868	12,624	115,097	56,962	1,299	59,455	3,043	329,794	6.8
1963	22,455	9,291	54,314	8,992	106,101	46,810	1,081	101,094	3,725	353,863	6.4
1964	26,558	7,913	55,851	9,015	162,249	69,229	2,552	79,900	6,847	420,114	6.3
1965	31,084	7,627	58,052	5,342	150,415	108,147	2,207	62,287	6,101	431,262	7.2
1966	29,871	7,617	84,584	9,584	231,482	117,553	1,336	83,275	13,859	579,161	5.2
1967	29,852	12,571	73,860	7,808	224,257	87,592	1,804	70,613	8,266	516,623	5.8
1968	34,103	25,193	97,941	11,317	291,642	132,006	10,572	119,013	13,243	735,030	4.6
1969	75,802	31,879	101,170	10,951	336,978	133,429	38,531	145,885	13,243	887,868	8.5
1970	51,205	42,460	93,977	14,620	329,030	207,270	48,069	245,022	79,716	1,111,369	4.6
1971	74,835	60,709	112,934	110,001	344,767	235,109	64,000	231,164	73,804	1,308,323	5.7

Source: Sea and Inland Fisheries Annual Reports of the Fisheries Division of the Department of Agriculture and Fisheries, Dublin.

TABLE 6

THE AVERAGE FIRST SALE PRICES OF OYSTERS IN IRELAND AND THE UNITED KINGDOM FROM 1926 TO 1970

Period	Ireland	United Kingdom
1926-1935	0.48	0.92
1936-1945	0.87	1.13
1946-1955	1.18	1.81
1956-1965	1.43	2.01
1966-1970	2.51	3.26

(a) Landings and Values at the Clarinbridge Public Oyster Fishery.

The numbers and values of oysters landed at the Clarinbridge Public Oyster Fishery from 1946 to 1971 are presented in Table 7(a). The proportion of the total Irish landings contributed by the Clarinbridge fishery is given in brackets.

The 1946 landings were the highest on record, presumably as a result of the reduced fishing effort during the Second World War. Landings declined during the early 1950's but rose again between 1957 and 1962. Since the latter date they have fluctuated between 340,200 and a peak of 670,000 in 1969. Provisional figures for 1971, however, suggest a heavy drop in landings and this will be discussed in a later section.

The total value of landings has generally followed the pattern of the numbers landed, although reference to the third column of Table 7(a) will show that the price of oysters at first sale, whilst fairly constant between 1947 and 1957, rose faster than the landings during the 1960s.

It will also be noted that between 1946 and 1960, Clarinbridge oysters accounted for most of the oyster landings in Ireland and in some years (e.g., 1958) commanded substantially higher prices than oysters from other areas. However, during the last decade landings have increased considerably at the Tralee fishery which is now the leading Irish oyster fishery. Nevertheless, Clarinbridge oysters still command a higher first sale price than Tralee oysters (e.g., £3.50 and £3.00 per long hundred respectively in 1971).

Table 7(b) presents the landings in terms of total weights and meat weights landed at Clarinbridge. These weights are very small compared with the weights landed in other European countries (Table 1).

TABLE 7a.

OYSTER LANDINGS AT THE CLARINBRIDGE PUBLIC OYSEER FISHERY

1946 TO 1971

Numbers, values, and Individual Values of Oysters*

Year	Number	Values (£)	Value of one oyster (p.)
1946	684,180 (53)	9,503 (54)	1.4
1947	75,335 (47)	5,282 (44)	1.1
1948	342,939 (33)	4,082 (33)	1.2
1949	399,882 (63)	3,971 (54)	1.0
1950	309,330 (70)	3,068 (68)	1.0
1951	204,876 (81)	2,602 (81)	1.3
1952	315,642 (75)	3,726 (78)	1.2
1953	499,212 (78)	5,151 (79)	1.0
1954	229,887 (57)	2,737 (51)	1.2
1955	204,300 (76	2,432 (79)	1.2
1956	219,138 (86)	2,323 (86)	1.1
1957	450,000 (84)	4,464 (83)	1.0
1958	420,000 (69)	7,827 (88)	1.9
1959	552,000 (86)	8,280 (87)	1.5
1960	501,660 (42)	6,166 (52)	1.2
1961	598,500 (43)	6,650 (46)	1.1
1962	552,000 (32)	6,900 (31)	1.3
1963	407,000 (31)	9,777 (44)	2.4
1964	340,200 (28)	7,425 (28)	2.2
1965	370,000 (25)	6,974 (22)	1.9
1966	441,000 (32)	8,750 (29)	2.0
1967	405,600 (30)	10,140 (34)	2.5
1968	548,720 (36)	13,198 (41)	2.5
1969	670,000 (25)	23,732 (31)	2.6
1970	540,000 (33)	20,000 (39)	4.1
1971	268,000 (9)	7,300 (10)	3.0

*Figures supplied by the Fisheries Division of the Department of Agriculture & Fisheries, Dublin.

TABLE 7b.

OYSTER LANDINGS AT THE CLARINBRIDGE PUBLIC OYSTER FISHERY 1946 TO 1971

Total weight and meat weight of oysters

Year	Estimated Total Weight (1)	Estimated Meat Weight (1)
1946	47.89	6.16
1947	33.27	4.28
1948	24.01	3.09
1949	17.99	3.60
1950	21.65	2.78
1951	14.34	1.84
1952	22.10	2.84
1953	34.95	4.49
1954	16.09	2.07
1955	14.30	1.84
1956	15.34	1.97
1957	31.50	4.05
1958	29.40	3.78
1959	38.64	4.97
1960	35.12	4.52
1961	41.90	5.39
1962	38.64	4.97
1963	28.52	3.67
1964	23.81	3.06
1965	25.90	3.33
1966	30.87	3.97
1967	28.39	3.65
1968	38.41	4.94
1969	46.90	6.03
1970	37.80	4.86
1971	18.76	2.41

(1) Metric Tons

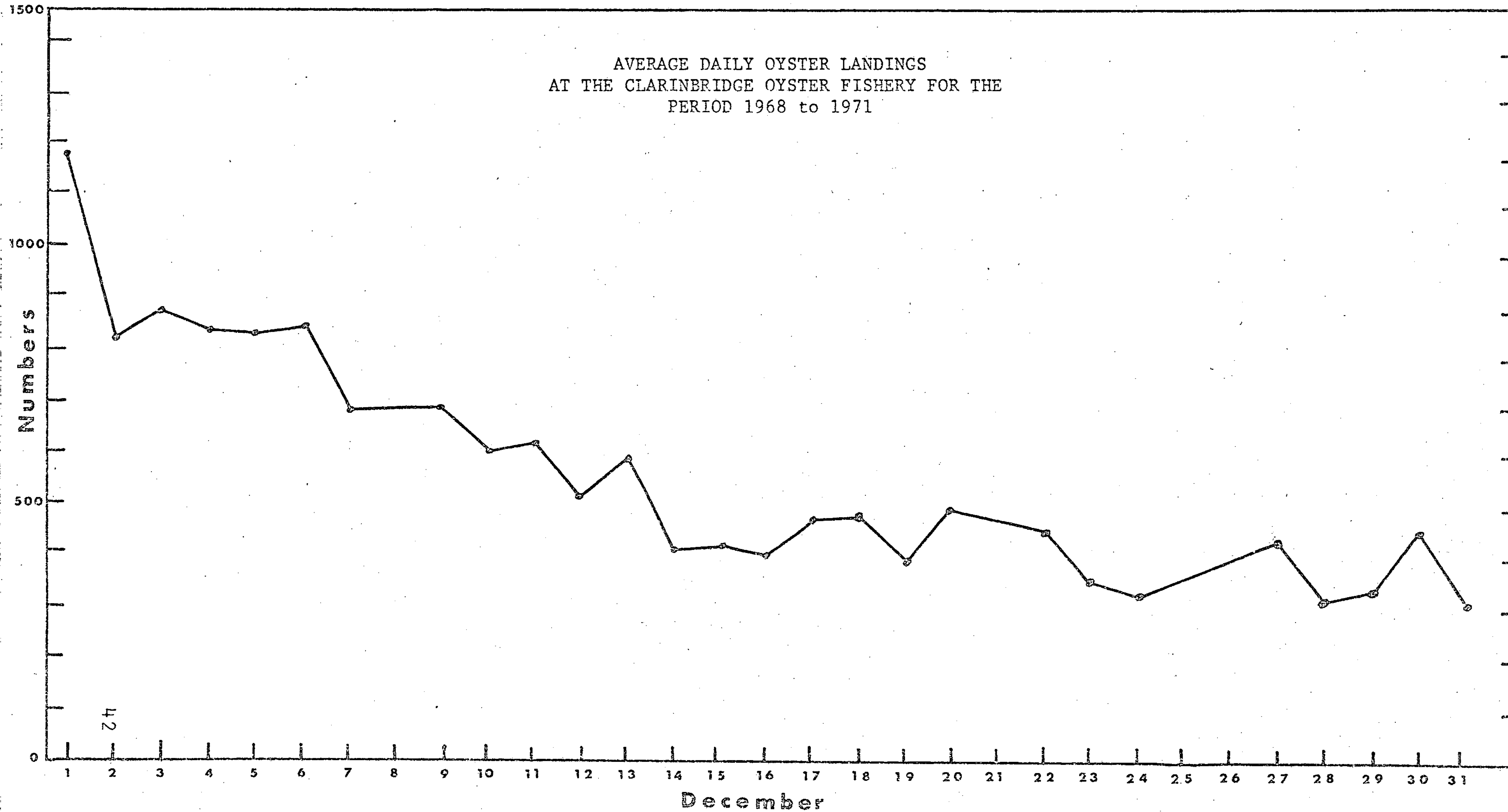
(b) <u>Daily Landings</u>

Figure 1 shows the average daily landings of several boats during the fishing seasons of 1968 to 1971. Typically, catches are highest on the first day and remain high during the first week of fishing. During the second week they decline sharply as commercial oysters become more difficult to catch. During the third and fourth weeks, catches tend to level off at about 300 oysters per day for the better fishermen.

Daily catch record sheets were returned by a number of fishermen and the most reliable figures for the 1970 and 1971 fishing seasons are presented in Table 8. However, it must be emphasised that these returns were generally made by the best fishermen and, therefore, the figures given in Table 8 are above the average which would be expected for all the boats engaged in the fishery.

The total landings of the few boats considered in Table 9 were generally smaller in 1971 than in 1970 as was the catch per boat per day. However, in 1970, Boat 1 was fished with twice the effort employed in 1971, when nearly half the 1970 catch was landed in fewer days fishing. Boat 2 caught more oysters in 1971 than in 1970 but its average daily catch was lower because it fished for longer in 1971. Boat 3 caught about half as many oysters in 1971 as in 1970, in just over half the time with the result that the average daily catch was similar in both years. Boat 4 had a poor season in 1971, with a reduced total catch and a halved average daily catch.

FIGURE 1



AVERAGE DAILY OYSTER LANDINGS
AT THE CLARINBRIDGE OYSTER FISHERY FOR THE
PERIOD 1968 to 1971
Numbers
1500
1000
500
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
December
42

TABLE 8

OYSTER LANDINGS OF INDIVIDUAL BOATS AT THE CLARINBRIDGE PUBLIC OYSTER FISHERY

In 1970 and 1971

Boat	1		2		3		4	
Date	1970[b]	1971[c]	1970[d]	1971[d]	1970[e]	1971[c]	1970[d]	1971[d]
1	1,638	900	1,386	1,110	1,008	977	1,650	-
2	1,260	756	504	756	630	438	732	-
3	1,512	600	1,004	660	567	378	762	-
4	816	666	756	786	630	378	612	129
5	1,194	-	630	-	564	-	762	-
6	-	714	-	756	-	378	-	612
7	1,260	438	504	690	564	378	-	693
8	-	-	-	-	-	-	-	490
9	1,050	468	504	564	564	378	618	480
10	690	438	504	378	564	312	528	400
11	792	534	504	450	315	-	690	485
12	564	-	504	-	504	-	516	-
13	-	252	-	474	-	-	-	-
14	648	-	378	126f	315	90	378	250
15	444	-	378	-	315	-	330	263
16	816	312	378	408	189	-	126	160
17	-	-	-	378	189	-	-	275
18	612	-	-	-	315	-	-	-
19	534	-	-	-	189	-	-	-
20	-	-	-	-	-	-	-	-
21	-	-	-	312	-	-	-	-
22	-	378	-	414	-	-	-	125
23	-	-	-	90f	-	-	-	252
28	-	-	-	-	-	-		252
29								252
Total Catch	13,830	6,456	7,934	8,352	7,422	3,707	7,704	5,218
No. Days Fishing	15	12	13	16	16	9	12	16
Average Catch/day	922	538	610	522	464	412	642	326

Key:-

a = actual number of oysters
b = 2 men fishing 2 dredges
c = 1 man fishing 1 dredge
d = 2 men fishing 1 dredge
e = 2 men fishing 1 dredge for first 10 days; 1 man subsequently
f = stormy = ½ day.

Table 9 gives a breakdown of the landings of Boat 1 for the seasons 1969 to 1971. It will be noted that the average daily catch in 1971 was greater than half that of the previous three years when twice the fishing effort was employed. However, it may be speculated that, had fishing been continued in 1971, the average daily figures would have dropped considerably as a result of diminishing landings and fatigue on the part of the fisherman.

(c) Fishing Effort

The numbers of boats, crew and dredges engaged in the Clarinbridge oyster fishery in 1970 and 1971 are given in Table 10.

(i) The number of dredge-hauls per day

The number of dredge-hauls made per day, per boat, or by individual fishermen is highly variable and depends on the following:

(1) the weather -- dredging is more difficult in rough weather;

(2) the nature of the seabed -- dredging is more difficult on mud than on shelly ground;

(3) fatigue -- fishermen tend to work harder at the beginning of the season and after a day's rest;

(4) catches -- larger catches tend to stimulate the effort;

(5) prices -- if low prices are expected, effort will be reduced, particularly if catches are also small (e.g., 1971);

(6) other activities -- e.g., if there is farmwork to be done, most Clarinbridge fishermen will give it precedence

TABLE 9

OYSTER LANDINGS OF ONE BOAT AT THE
CLARINBRIDGE PUBLIC OYSTER FISHERY
IN 1968, 1969, 1970 AND 1971

Date	1968[a]	1969[a]	1970[a]	1971[b]
1		2,928	1,638	900
2	1,740	1,512	1,260	756
3	1,398	1,638	1,512	600
4	1,554	1,134	816	666
5	1,584	1,416	1,194	-
6	1,134	1,320	-	714
7	1,140	-	1,260	438
8	-	-	-	-
9	984	1,134	1,050	468
10	900	1,110	690	438
11	1,050	1,362	792	534
12	612	732	564	-
13	642	942	-	252
14	954	-	648	-
15	-	570	444	-
16	696	756	816	312
17	312	942	-	-
18	660	978	612	-
19	468	588	534	-
20	672	438	-	-
21	-	-	-	-
22	-	468	-	378
23	252	384	-	-
24	-	-	-	-
25	-	-	-	-
26	-	-	-	-
27	252	126	-	-
28	450	-	-	-
29	-	408	-	-
30	480	-	-	-
31	276	234	-	-
Total Catch	18,210	21,120	13,830	6,456
No. Days Fishing	22	22	15	12
Average Catch per day	828	960	922	538

Key:-

a = 2 men fishing 2 dredges; b = 1 man fishing 1 dredge

TABLE 10

BOATS, ENGINES, DREDGES AND CREWS ENGAGED IN THE CLARINBRIDGE PUBLIC OYSTER FISHERY IN 1970 AND 1971.

(a) 1970

Type of Boat	Engine	No. of Boats	No. of Crew Per Boat	No. of Dredges
"Púcán"	-	9	2	9
"Púcán"	Outboard	3	1	3
"Púcán"	Outboard	51	2	51
"Púcán"	Inboard	11	2	12
20-26ft.	Inboard	7	2	9
26-32ft.	Inboard	4	2 - 4	8
Total		85	170	92

(b) 1971

Type of Boat	Engine	No. of Boats	No. of Crew Per Boat	No. of Dredges
"Púcán"	-	5	2	5
"Púcán"	Outboard	8	1	8
"Púcán"	Outboard	43	2	43
"Púcán"	Inboard	2	2	2
20-26ft.	Inboard	1	1	1
26-32ft.	Inboard	3	2 - 3	3
Total		62	116	62

over oyster fishing.

No counts of dredge-hauls per day were made by the author but the general concensus of opinion, voiced by the fishermen, was that two men working one dredge could take a maximum of about 100 hauls per day in ideal conditions. Generally, however, a figure of about 70 hauls per day would be more realistic.

(ii) Catch per unit effort

Catch per unit effort data for the 1970 and 1971 fishing seasons, presented in terms of "dredge days", are given in Table 11. The cumulative total number of dredges employed each day gives an indication of the total effort for a particular season. In 1971, when boats were permitted to use one dredge only, the number of "dredge days" is equal to the number of "boat days" fished.

The use of "dredge days" as a unit of fishing effort provides greater accuracy than figures obtained by dividing the total catch by the number of boats fishing. However, it does not take into account the number of dredge-hauls made by each boat -- a figure which would provide the most accurate estimate of catch per unit effort.

In 1971, the total number of boats fishing and the total landings were considerably less than in 1970. More days were fished in 1971 than in 1970 but the cumulative number of "dredge days" was lower in 1971 as was the average catch per day indicating that the catch per unit effort had also dropped. Had the 1970 catch per unit effort been maintained a total catch of nearly 400,000 oysters would have been expected.

The drop in catch per unit effort in 1971 can be attributed to the following:-

(1) bad weather for part of the season which made dredging difficult;

(2) lower catches which discouraged greater effort on the part of the fishermen; and

(3) Lower prices which further discouraged physical effort.

TABLE 11

THE CUMULATIVE NUMBER OF "DREDGE DAYS"
AT THE CLARINBRIDGE PUBLIC OYSTER FISHERY
IN 1970 AND 1971

Date	1970		1971	
	No. Dredges	Cumulative Total	No. Dredges	Cumulative Total
1	92	92	62	62
2	55	147	60	122
3	58	205	53	175
4	27	232	53	228
5	53	285	-	228
6	-	285	56	284
7	64	349	53	337
8	-	349	-	337
9	68	417	50	387
10	65	482	48	435
11	56	538	46	481
12	56	594	-	481
13	-	594	35	516
14	42	636	6	522
15	56	692	6	528
16	37	729	15	543
17	50	779	24	567
18	52	831	15	582
19	51	882	-	582
20	Fishery Voluntarily		-	582
21	Terminated		6	588
22			10	598
23			16	614
24			16	630
25			-	630
26			-	630
27			4	634
28			4	638
29			2	640
30			2	642
31			2	644
Total		882		644
Total landings		538,800		268,000
Catch per dredge per day		611		416

It will be shown in Chapter V that the number of oysters available for fishing in 1971 was similar to that of 1970, so the drop in catch per unit effort cannot be attributed to a reduction in available stocks.

(d) <u>The distribution of oysters among Clarinbridge buyers</u>

Table 12 shows the approximate distribution of oysters amongst Clarinbridge oyster buyers after the 1969, 1970 and 1971 fishing seasons. The figures were collected by the author and do not necessarily tally with official figures presented elsewhere. In some cases the numbers and values may be underestimated but they were the best available at the time of writing.

(e) <u>Prices</u>

The average price paid for oysters at first sale in 1969 was about £4.00 per long hundred, in 1970 about £4.75 and in 1971 about £3.50. The drop in price in 1971 was due, firstly, to the difficulty in selling oysters on the Continent where better quality French oysters were cheaper than Irish oysters (Hugman, pers. comm.) and, secondly, to the absence of the Clarinbridge Oyster Co-operative which had artificially raised the 1970 prices by buying oysters in straight hundreds for the prices given by other buyers for long hundreds.

TABLE 12 THE DISTRIBUTION OF OYSTERS AMONG CLARINBRIDGE BUYERS FROM 1969 TO 1971

Oyster Buyers	1969			1970			1971		
	Actual Numbers	Estimated Cost (£) [a]	No. boats bought (b)	Actual Numbers	Estimated Cost (£)	No. boats bought (b)	Actual Numbers	Estimated Cost (£)	No. boats bought
1	189,000	6,000		101,000	3,800	12	37,000	1,100	7
2	252,000	8,000		163,800	6,000	30	63,000	1,750	20
3	101,000	3,200		54,300	2,050	10	76,000	2,250	18
4	50,400	2,000		31,500	1,400	8	44,000	1,300	11
5	43,000	1,400		25,200	950	4	---	---	-
6	159,000	6,800		79,000	3,750	13	---	---	-
7	---	---		84,000	4,000	10	---	---	-
8	---	---		---	---	-	28,000	900	4
Unsold (c)	---	---		---	---	-	20,000	---	-
Total	794,400	27,400		538,800	22,000	87	268,000	7,300	60

(a) Author's estimate
(b) Approximate figure
(c) Sub-legal size oyster

THE OYSTER FISHERY

(a) Oyster Fishermen

Currently about 300 fishermen engage in part-time oyster fishing in Ireland. Nearly 200 of these fish at Tralee, between October 16th and the end of February. Many of those participating in the fishery are professional fishermen who fish for lobsters, crabs, crawfish, scallops and salmon from about April to the end of September. In contrast, at Clarinbridge, where the fishing season lasts only one month, most of the fishermen are professional farmers who live near the fishery and do not engage in any other remunerative fishing activities during the rest of the year.

Most of the Clarinbridge fishermen come from the parishes of Maree, Oranmore, Clarinbridge, Kinvara and Ballindereen. A few "outsiders", usually from Galway or Connemara, participate in the fishery, but recent legislation limiting the number of dredges per boat and size of dredges (see later) has discouraged most of the "outsiders" from entering the fishery.

During December, when there is little work to be done on the land, two men, fishing one dredge from a 16ft. púcán, can earn up to £200 each when catches are good (about 10,000 oysters per boat) and prices are high (£4-£5 per long hundred). This income is often used to cover overheads on the farms, many of which are too small to be economically viable alone.

In a poor season, such as 1971, earnings may scarcely cover the cost of running the boat and maintaining it unused for the other eleven months of the year.

(b) Oyster Farmers

Since oyster farming has been revived only recently in Ireland there are few actual or potential oyster farmers in the country. Those currently active in the industry can be divided conveniently into two categories; those with long experience of oyster farming who enjoy the occupation and are satisfied with the moderate income it provides and secondly, businessmen who see oyster farming as a high risk business which could bring them quick profits. Those in the latter category generally have little or no knowledge of oyster farming and need to employ experienced managers to run their oyster farms.

(c) Oyster Buyers

Oyster buyers can be placed in three categories: firstly, the fisherman or local farmer who has saved enough capital to buy oysters and has found a market for them; secondly, the private oyster farmer who will relay the oysters for fattening them or sell them directly, usually to assured markets on the Continent; and, thirdly, there is the fish merchant who handles oysters along with other species and sells them either locally or to agents elsewhere.

(d) Boats and Engines

The majority of boats employed at the Clarinbridge fishery are 12 to 16 ft. púcán-type craft, crewed by one or two men. They are locally built wooden craft of considerable strength and stability. They are suitable for hand kedging or power dredging, with 3 to 20 h.p. outboard engines. Inboard engines have been installed in some of these boats but they create cramped working conditions on board. Several larger boats, including 32ft lobster boats, also participate in the fishery. All these have inboard engines and are generally crewed by 2 to 4 men.

Dredges are hand-hauled on all but the largest boats at the Clarinbridge fishery, but at Tralee, over 20% of the boats use power haulers. On private fisheries, when dredging is employed, power haulers are usually used to lift the dredges.

Table 10 lists the types of boats employed at the Clarinbridge fishery in 1970 and 1971.

(e) The Fishing Season

The season during which oysters are fished and eaten in Ireland is reflected in the old maxim that oysters should be eaten only during months with an 'r' in their names, that is, from September to April, inclusive. The fishing season is limited to this period for two reasons: firstly, because oysters are generally unsuitable for consumption during the breeding season, which extends from May, when the gonads start to develop, to the end of August; secondly, because regular disturbance by dredging and handling upsets the growth of the oyster, which occurs mainly in the summer, and thereby reduces the potential production.

Private oyster grounds can be fished at any time of the year but usually dredging is confined to the above mentioned season. Fishing on public fisheries is, however, limited by law. At Tralee Bay Public Oyster Fishery, fishing can be pursued only from October 16th to the last day of February, [3] from Monday to Friday inclusive,[1] and between 10.00 a.m. and 5.00 p.m. on the appointed days.[2] (1. - Tralee Bay Oysters Bye-Laws, No. 534, 1966; 2. - No. 544, 1968; 3. - Tralee Bay Oysters Close Season Bye-Law, No. C.S. 115, 1968).

Fishing at the Clarinbridge Public Oyster Fishery is limited to the month of December but dredging is allowed every day between sunrise and sunset.

(f) Other Regulations Applying to Public Oyster Fisheries

A number of important conservation measures have been incorporated into the fishery regulations governing the Tralee and Clarinbridge oyster fisheries. These are concerned mainly with the size of oysters taken from the beds and the means by which they are removed.

The following are the relevant regulations which became law on the 1st day of Octobrt, 1966, as the Tralee Bay Oysters Bye-law, No. 534, 1966 and "apply in relation to all persons engaged in fishing for or taking oysters on or from the Tralee Bay oyster beds." All previous regulations relating to this fishery have been revoked.

(i) all such oysters as may be taken or caught shall be culled;

(ii) any oyster which measures less than three inches at its greatest dimension shall not be taken away but shall immediately be thrown back into the sea;

(iii) all gravel and fragments of shell raised or taken shall immediately be thrown back into the sea;

(iv) no more than one dredge shall be used from a boat at a particular time;

(v) the mouth of any dredge shall not exceed four feet measured along its longest side;

(vi) no boat shall have on board, during the close season for oysters in the Tralee Bay oyster beds, any dredge or other instrument for taking oysters;

(vii) during the month of October in any year no oyster shall be removed or taken from the Tralee Bay oyster beds by any means whatsoever save by dredging.

Similar regulations apply at Clarinbridge Public Oyster Fishery but these have not been brought up to date as have the Tralee Bay oyster bye-laws. Several of the regulations which apply at Clarinbridge cover all the oyster beds in Galway Bay. For example, the fishing season was limited to the month of December by a bye-law dated August 13th, 1877, and a bye-law dated May 7th, 1908, set the legal minimum size limit for oysters taken from Galway Bay at three inches.

The first bye-law to apply solely to the Clarinbridge Public Oyster Fishery was passed on October 5th, 1944, and this prohibited the taking of oysters by any means other than by a dredge or net-fished from a boat (i.e., it prohibited hand-picking).

A new bye-law dated November 4th, 1971, brought regulations at Clarinbridge into line with parts (iv) and (v) of the Tralee Bay Oysters Bye-Law No. 534, 1966. Prior to 1971, any number of dredges of any size could be fished from boats of any dimensions. In effect, the new bye-law has limited the size of dredges used to the standard 3ft. 6in. or 4ft. Clarinbridge dredge and limited the maximum size of boats which can fish economically at Clarinbridge to about 26ft. by prohibiting the use of more than one dredge per boat.

(g) Regulations Applying to Private Oyster Fisheries

There are several types of private oyster fishery:-

(i) Chartered oyster fisheries -- oyster fisheries which were claimed by virtue of a grant or lease from the Crown and which are usually associated with grants of land. This type of fishery agreement cannot be revoked by the State. The St. George Oyster Fishery, which lies adjacent to the Clarinbridge fishery is held by virtue of a Ministerial Order of 1960.

(ii) Licensed oyster fisheries -- areas of seabed granted, under section 245 of the Fisheries (Consolidation) Act, 1959, to an individual or company by the state to form or plant an oyster bed subject to the following regulations:* (1) that the licensee shall comply with the provisions of the

*Quoted from an actual licence

Foreshore Act, 1933; (2) that within three years from the date of licence proper steps shall be taken to form an oyster bed; and (3) that the oyster bed ground shall at all times be properly cultivated.

Prior to the granting of a licence any objections to the establishment of an oyster fishery must be considered at a public enquiry **usually chaired by the Inspector of Fisheries and Scientific Adviser.**

Currently, there are about 40 licensed oyster beds listed by the Fisheries Division of the Department of Agriculture and Fisheries (Duggan, pers. comm.), but the majority of these should have been revoked because the grounds have not been cultivated during recent years.

(iii) Ordered oyster fisheries -- areas of seabed granted under the 1959 Act to individuals or companies giving them "exclusive right of depositing, propagating, dredging and fishing for and taking oysters, and in the exercise of that right, may within the limits of the said fishery, make and maintain oyster beds, and at any season collect oysters and remove them from place to place as and when the individual (or company) thinks fit and do all other things which the individual (or company) thinks proper for obtaining, storing and disposing of the produce of the said fishery, and for the regulation of the said fishery." A Public Enquiry is necessary **after the Minister has given notice of his intention to consider an application.**

(iv) Unlicensed oyster fisheries -- oyster layings which cannot be legally protected because they are not held under Charter, Licence or Order. The ownership of the oysters is, however, held in public respect and the layings generally survive unmolested. The shore layings of most of the oyster buyers at Clarinbridge belong to this category.

~~(v) Privately-owned oyster fisheries -- areas of seabed held under Charter or leased under freehold, e.g., several of the private oyster beds in Galway Bay~~.

METHODS AND GEAR FOR COLLECTING AND HANDLING OYSTERS

Oysters occur in varying depths of water from the intertidal zone, where the seabed is uncovered at low spring tides, to depths in excess of thirty feet. Therefore, a variety of methods may be required to harvest oysters from any particular locality. Thus, over the centuries, harvesting techniques have developed through several stages from hand picking to power dredging and sophisticated hydraulic methods currently employed on some American oyster fisheries. The harvesting methods employed in Ireland at the present time will be considered below.

(a) Handpicking

The earliest collections of oysters were made by hand from the shore or exposed banks at low spring tides. Today, however, handpicking is practised only on a limited scale in Ireland on small natural oyster beds and on private fisheries. The natural beds generally yield only a few dozen oysters at each good tide and these are collected by the local inhabitants for their own consumption. On private fisheries, however, handpicking is often the most efficient way of collecting oysters from densely stocked grounds because mechanical methods, such as dredging are highly inefficient (see later) and damaging to the oysters.

Handpicking was prohibited at the Clarinbridge Public Oyster Fishery in 1944 (see earlier) as a conservation measure (Went, 1962) and the fishery baliffs are required to patrol the shores whenever any part of the oyster grounds are left uncovered. Went suggested that handpicking was disadvantageous to the oyster stocks because small oysters were often trodden into the seabed, thereby reducing future stocks. However, it could also be argued that handpicking alone would aid in the conservation of stocks by leaving sub-littoral stocks unfished and undamaged by dredging.

(b) Dredging

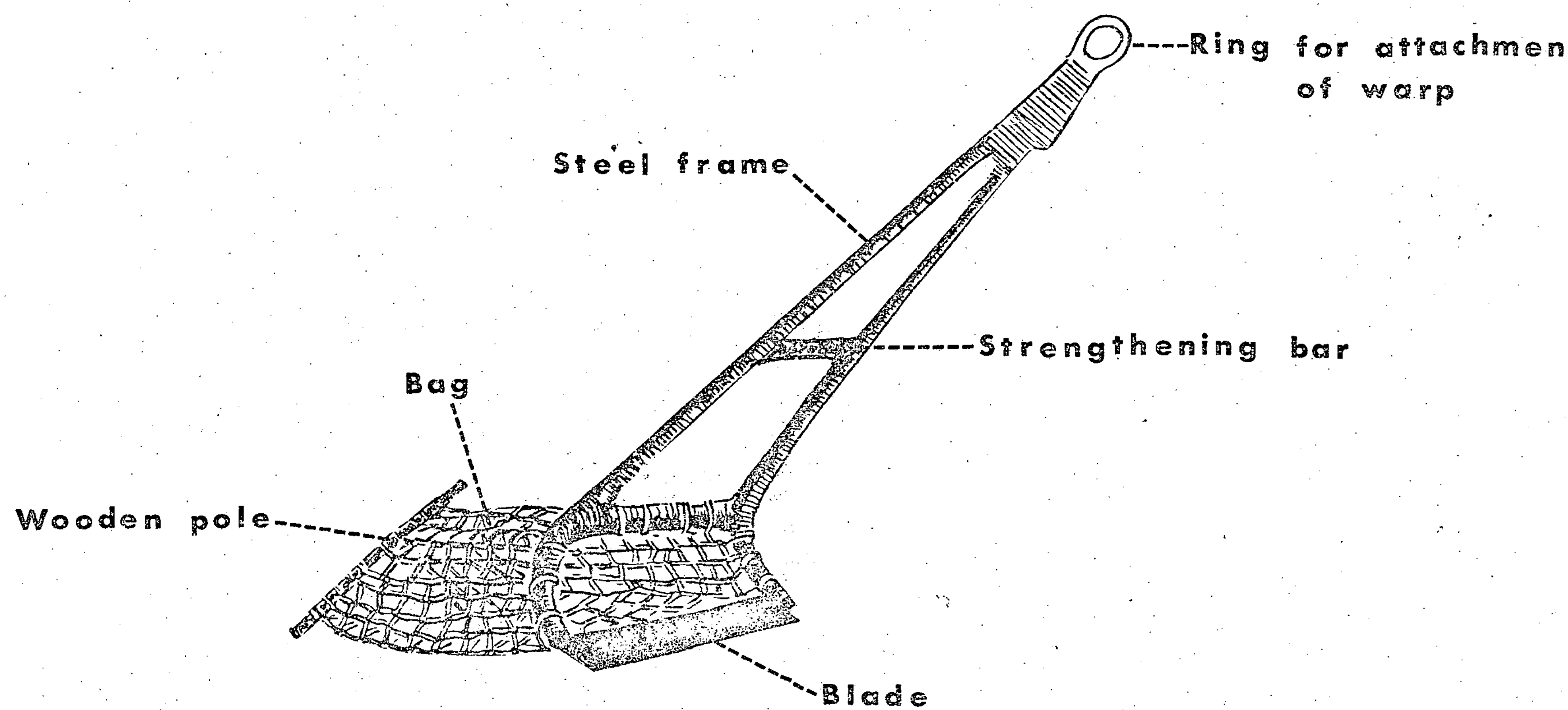
Dredging is a method that developed as an improvement on long handled rakes and tongs for fishing oysters from greater depths (Medcof, 1961). The purpose of dredging is usually to skim off the oysters, cultch and rubbish from the bottom without digging into the seabed (Cole, 1956). The depth to which the dredge digs into the material on the seabed can be regulated by varying the length of warp used; with too much warp the dredge digs in and fills up with mud and with too little it tends to skip over the bottom without catching the oysters (Hugh-Jones, pers. comm.). Usually, dredges are towed with the tide and are most effective towards low water. However, even a well-operated dredge is a highly inefficient instrument for catching oysters and catch efficiency, even on densely stocked oyster grounds, has been rated as low as 5-20% (Key, pers. comm.).

The standard Clarinbridge hand-operated oyster dredge (Figure 2) is of typical design. It comprises a triangular mild steel frame with attached bag; the frame consists of two long limbs connected to a flat bar or blade which is scraped along the seabed. The dredge is fastened to a tow rope by means of a ring, secured at the apex of the frame. A strengthening bar may be fixed between the two long limbs. The Clarinbridge dredge measures 3ft. 6ins. to 4ft. across the mouth -- and as a result of recent legislation (see earlier) may not now exceed the latter dimension. The dredge bags are made of materials which vary with availability and locality. At Clarinbridge they are generally made with nylon twine, but in some areas interlocking galvanised wire rings are incorporated into the designs. Usually a wooden pole is attached to the end of the bag to give it buoyancy in the water and, presumably, to prevent the bag "blowing out the wrong way" when the dredge is shot. Occasionally, toothed scallop dredges are used to fish oysters and these are said to be more effective than standard dredges on dirty ground.

In the past, dredges were operated from sailing boats (e.g., in Essex and off the Wexford Coast) and from rowing boats, as was customary on the west coast of Ireland. Today, the former method is obsolete in Europe (although dredging under sail for <u>C. virginica</u> is still carried out in Chesapeake Bay

FIGURE 2.

A STANDARD CLARINBRIDGE OYSTER DREDGE



on the east coast of the U.S.A., Loosanoff, 1965) but fishing from rowing boats still persists at Clarinbridge where it is known as hand kedging. This strenuous method is pursued by two men, usually working a 16ft. "púcán". An anchor, with a rope attached, is shot over the bow and the boat is rowed away from the anchor until the rope is paid out. The dredge is then shot over the stern of the boat and by a combination of rowing and hauling on the anchor the dredge is dragged over the oyster bed. The dredge is hauled, the catch is deposited in the boat and sorted and the procedure is repeated several times in a circle around the anchor until the area has been thoroughly fished.

Hand kedging is gradually dying out at Clarinbridge as motor-powered boats gain popularity. However, kedging still holds an advantage over powerboat fishing at Clarinbridge in that during a poor season, fishermen employing this method do not suffer the financial losses incurred by those who are obliged to run and maintain engines during the fishing season.

Powerboats are a recent innovation at Clarinbridge although they have been employed at Tralee and elsewhere in Europe for many years. In 1965, only three powerboats were employed at Clarinbridge; in 1966 there were five and by 1970 the number had risen to seventy-six, with a corresponding decline in the number of rowing boats to nine. In December, 1971, the number of powerboats dropped to fifty-seven as a result of the new bye-law mentioned previously, which limited the number and size of dredges which could be used at the fishery. The number of rowing boats again dropped, to five.

The increase in powerboat fishing at the Clarinbridge fishery has had a noticable, but as yet unquantified, effect on the oyster bed. Dredging with powerboats has enabled fishermen to cover large areas more effectively than was possible with rowing boats and, as a result, fishing at the periphery of the bed, where oysters occur at low densities (see later), has become worthwhile. Furthermore, continuous dredging is possible with powerboats and no time is lost sorting the catch and rowing, as is the case with hand kedging. Furthermore, since the catch taken by powerboats can be sorted while they are still dredging,the excess cultch, small oysters and rubbish can be distributed more evenly over the seabed than was possible from stationary rowing boats. Thus, the piling up of such material, which often resulted in the smothering of small oysters, is avoided (personal observation). Another benefit of powerboat dredging is that more and longer hauls can be made per day, thereby increasing the possibility of larger catches. Finally, it can be surmised that the cleaning effect of dredging -- the release of silt and weed accumulated over the previous year -- will have increased with the introduction of powerboat dredging.

(c) Other Methods

In addition to handpicking and dredging there are a number of other, specialised, methods employed to harvest oysters from the seabed. However, since these methods are not used extensively in Ireland, they will only be discussed briefly.

(i) S.C.U.B.A. diving

Underwater diving using self-contained underwater breathing apparatus (S.C.U.B.A.) is used to collect oysters and service installations on the seabed in many parts of the world today. In Ireland, it is employed on private oyster fisheries and in research, but otherwise it is illegal to collect any shellfish from public waters by diving (Special Government Order, 1966). Diving is valuable to the oyster farmer because it enables him to see and handle oysters and materials which he would otherwise have to work with remotely from the surface. Its use, however, is limited by adverse weather conditions, cloudy water, the health of the diver, the limited time any one diver can remain underwater and the cost of equipment.

(ii) Escalator harvesters and suction dredges

These recently developed mechanised fishing devices are used mainly in the U.S.A. According to Medcof (1961), the escalator harvester takes a higher proportion of oysters from the bottom and causes less bottom disturbance than any other gear tested. However, such devices can only be used economically on large uniform oyster beds and are not, therefore, suitable for use in Ireland at the present time.

Handling Oysters

Oysters pass through several stages of handling between leaving the seabed and reaching the consumer. The handling procedures which are most commonly practised at the public and private oyster fisheries on Galway Bay are described below.

The fishermen sort their catches on board and store their commercially valuable oysters in fish-boxes, sacks or wire baskets. At the end of the day, if they cannot sell their oysters directly for a satisfactory price, they tip them into stone circles (brocháns) situated at low water spring tide level. These circles are marked with each fisherman's own distinctive buoy, but as was mentioned earlier, once the oysters have been returned to the seabed the fishermen no longer have any legal claim to them.

The oysters are held until the next low spring tide, which is usually at the beginning of January, when the oyster buyers tour the stone circles to examine the oysters and fix a price. If a satisfactory price is not offered to the fishermen they will hold the oysters for several months, possibly until the next September, when the oysters will command a better price as a result of the extra season's growth.

When the price has been fixed the oysters are sold to the buyer in long hundreds (a long hundred at Clarinbridge is 126 oysters, comprising 21 'hands', a 'hand' presumably being the number of oysters a man can hold in one hand or at one time). He then transfers them to his own layings where they are stored until sale.

Price Fixing

Prices are generally fixed by agreement between oyster buyers after they have assessed the supply and demand for oysters in a particular season. If the fishermen are dissatisfied with the price they will hold their oysters in an attempt to force up the price. However, this action is usually only marginally successful since the buyers are currently working on small profit margins and cannot afford to pay higher prices.

Cleaning and Grading

When oysters are collected by the buyers they are generally covered with epifauna such as barnacles, tubeworms, saddle oysters and oyster spat. These animals soon die when exposed to the air and unles they are removed from the oyster shells they produce an unpleasant odour which is unacceptable to the handlers and consumers. Most of the small oyster dealers do not clean their oysters thoroughly and cannot, therefore, command a high price. Professional oyster farmers, however, employ extra labour to clean oysters before they are graded and marketed. Cleaning is still carried out most effectively by hand, using a heavy knife, since attempts to develop mechanical cleaners have met with only limited success.

Legal size oysters -- those which will not fit through a ring of 3 ins. (76mm) internal diameter -- range in size from 76 mm to over 100 mm in diameter and from less than 25 gms. to over 120 gms. in weight (see later). They must therefore be graded before sale. The local Clarinbridge oyster buyers, who have no facilities other than their shore layings for processing their oysters, generally grade their oysters subjectively. On the other hand, the professional oyster farmer in the area grades his oysters, by weight, with a mechanical grader in order to satisfy the European market which judges oysters by weight rather than size. The conventional European oyster grades are given in Table 13. below.

TABLE 13.

Grade	8	7	6	5	4	3	2	1	0	00	000
Minimum Weight (g)	25	30	40	50	60	70	80	90	100	110	120

In addition to size and weight, oyster quality is also judged on the plumpness and colour of the meat and the whiteness of the inner shell. Such qualities can generally be achieved by suitable cultivation techniques but is is impossible to check them before the oysters are marketed.

Packing and Distribution

Oysters are packed in a variety of containers, the type depending on the size and destination of the consignments. In small local transactions they may be packed in sacks or cardboard boxes, but for longer journeys, tea-chests, wooden boxes or polystyrene cases may be employed.

Since oysters are a heavy commodity they incur heavy freight charges, particularly when sent by air. Fortunately, however, they can survive out of water for several days in the right conditions and can therefore withstand longer, but cheaper, land and sea journeys. However, transportation by land and sea is difficult between Ireland and the Continent and most oysters must be flown out of the country -- thereby increasing their cost abroad.

Traditionally, Irish oysters were transported to Britain by sea for sale at Billingsgate and other large markets. Prior to Irish independence many English fish merchants had oyster layings in Ireland or bought oysters directly from Irish growers. However, Irish oyster production has diminished since that time and the export trade with Britain, which decreased correspondingly, has now virtually ceased.

Currently, the major markets for Irish oysters are in Belgium, Germany and Holland where they supplement the large imports of French oysters. This demand for Irish oysters on the Continent arose, as was pointed out earlier, after the severe winter of 1962-63 when oyster production in the rest of Europe was severely reduced. Exports have gradually increased since that time, although currently, it is difficult to market Irish oysters on the Continent where they are in direct competition with cheaper, better quality French oysters (Hugman, pers. comm.). The home market is very small; oysters are sold locally during the season or sent to hotels, mainly in Dublin, often in small batches numbering only a few dozen.

There is no demand for Irish oysters abroad for relaying because they do not survive well in foreign waters (Hugman, pers.comm.).

European flat oysters are sold fresh in the shell to the consumer or live to oyster farmers for fattening or relaying as breeding stock. The species is rarely processed, as are the cupped oysters *C. gigas* and *C. virginica*. This is partly because of the high price commanded by live flat oysters and partly because the Japanese and American species are less palatable when eaten raw.

Current Retail Prices

The price of oysters to the consumer varies enormously. At Clarinbridge they may be sold for as little as 73p per dozen, while more generally in Irish hotels they will command £1.50 to £2.50 per dozen. In Britain, prices in excess of £3.00 per dozen may be charged.

No continental retail prices can be given here, but it is reported that in 1971-72, Irish oysters were sold to shellfish dealers in Europe at a second sale price of £20-£70 per thousand (24p - 84p per dozen) according to the grades supplied.

CHAPTER III

ENVIRONMENTAL FACTORS

III. ENVIRONMENTAL FACTORS

Environmental fluctuations can have far reaching effects on the survival and distribution of a species. If the species is of commercial value slight changes in one or more environmental factors can seriously jeopardize the economic viability of a given project. Oysters are particularly susceptible to adverse environmental changes because of their complex life history and the delicate balance of their estuarine habitat.

During the pelagic phase the movements of the larvae are governed by the action of tides and currents which may, or may not, carry them to suitable sites for settlement. The growth and development of larvae are influenced by water temperature and also food supply, which may be limited if the discharge of nutrient-rich fresh water over the oyster bed is low during the breeding season.

The intensity of settlement is limited not only by number of larvae reaching maturity but also by the number of suitable sites for settlement on the seabed. Settlement sites must be free from fouling by silt and competitive organisms, but they must also occur in areas where strong currents are not prevalent.

In the sedentary phase, which occupies most of the oyster's life-history, the oyster must rely on water currents to bring its food and carry away its waste and reproductive products. It cannot retreat from adverse environmental conditions such as oxygen depletion, dessication, silting and changes in temperature and salinity and must rely on maintaining ambient conditions within its valves during such critical periods. Environmental fluctuations particularly affect reproduction and growth, as will be shown in Chapters IV and V.

The following sections outline the general environmental requirements of *Ostrea edulis* and detail the conditions prevailing at the Clarinbridge Public Oyster Fishery during the period 1968 to 1972.

1. Location of the oyster bed

The location of the oyster bed has been described in Chapter II and its position in relation to other oyster beds in Galway Bay is shown in Map 3. The exact location and extent of the oyster bed is given in Map 4.

2. Geology

The entire catchment area of the Clarinbridge estuary and the rivers which discharge into it is situated on Upper Carboniferous Limestone.

3. Hydrography

Ostrea edulis usually inhabits shallow estuarine areas (although deep sea oyster beds do exist) with moderate currents and tidal exchange. Generally the seabed is level and maintained free from excessive silt deposition by current action. Water depth varies from nil at low spring tides to a maximum of 10 to 15 metres at high water in some areas.

(a) Topography of the seabed

Although no detailed survey of the seabed in Clarinbridge estuary was made during these investigations, general observations indicated that the seabed is flat and sloping gently from Kilcolgan Point westwards. There is a channel, approximately 2m deep, running close to the north shore at Keave. At the western end of the oyster bed there are a number of shoals which are exposed at low spring tides and there is an almost permanently submerged bank near the north shore to the west of Black Weir pier.

(b) Currents

Current measurements made with "jelly bottles" (Carruthers, 1967) approximately 0.7m above the seabed, indicated current speeds of up to 0.45 knots over the oyster bed and 0.75 knots at Station III (Map 6, Chapter IV) on summer spring tides. These figures are lower than those recorded by Waugh (1957a) on the Essex oyster beds where speeds of 0.8 knots to 1.6 knots were not uncommon near the seabed on flood tides.

Currents are discussed in more detail in relation to larvae dispersal and spat settlement in Chapter IV.

(c) Tidal range and tidal exchange

The tidal range in Galway Bay varies from 2.0 metres on summer neap tides to 5.5 metres on equinoctial spring tides (Source - Galway Harbour Commissioners Tide Tables).

No estimate has been made of tidal exchange over the oyster bed but float tests (discussed in more detail in Chapter

IV) and current measurements suggested it may be quite slow since water stationed over the oyster bed at high tide does not flow much further than the western end of Eddy Island on the ebb.

(d) Water depth

Water depth ranges from nil at Keave to approximately 2 metres at the western end of the oyster bed at low water on winter spring tides and from about 5 metres to 7 metres at high water. In the summer, the depth ranges from about 1 metres to 6 metres at low water springs and from 4 metres to 9 metres at high water.

(e) Drainage

Two rivers discharge into the Clarinbridge estuary at the eastern end (Map 4). The Dunkellin River discharges the greater volume of fresh water into the estuary. The discharge of the Clarin River is low during the winter and negligible during the summer.

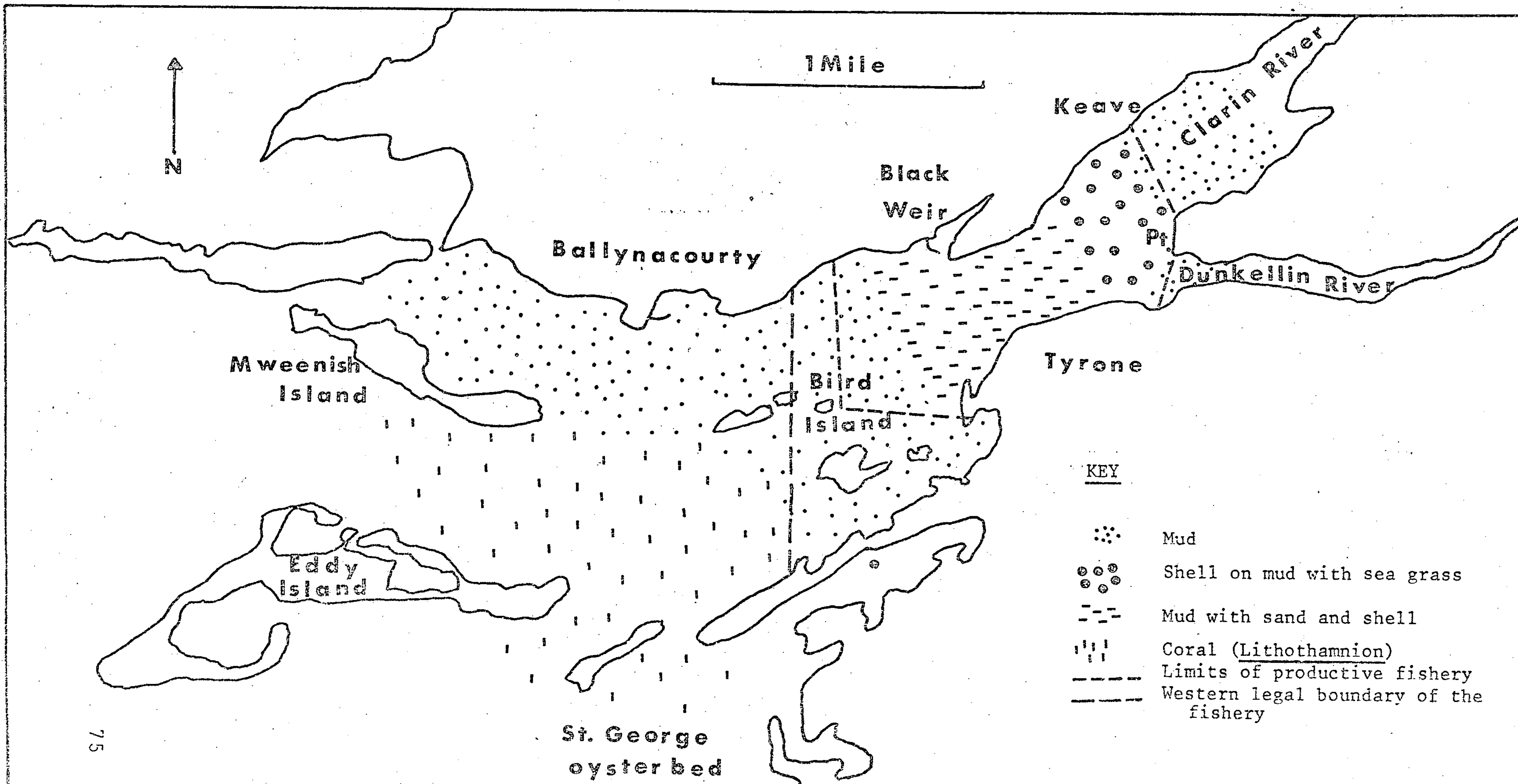
The catchment area around the oyster bed is small and runoff from the land has a negligible effect on the salinity of the estuary.

The discharge of the River Corrib at Galway, which reduces salinity in the bays to the north of Tawin Point, has little or no effect on salinity in the Clarinbridge estuary.

(f) Substrate

Ostrea edulis requires a firm substrate into which it can sink slightly in order to maintain its position against currents and other disturbances. The species usually occurs on predominantly muddy bottoms although it can thrive on stable sand or attached to rocks. If the substrate is too soft

MAP 5. THE GENERAL DISTRIBUTION OF SUBSTRATE TYPES AT THE CLARINBRIDGE PUBLIC OYSTER FISHERY



the oyster will sink and smother; if the substrate is sandy and unstable it will be buried.

The substrate of the Clarinbridge oyster bed was assessed subjectively by analysis of samples taken in grab surveys and by observations made by the author while diving. The general distribution of substrate types on the main part of the oyster bed and in adjacent areas is given in Map 5. The substrate to the south of Kéave is predominantly mud, overlain by entire and fragmented shells (mainly of oysters and clams) and stones, with sea grass (*Zostera*). Further west the seabed becomes muddier and the fragmented shells (mainly *Turitella communis*) and sand tend to be incorporated into the mud. To the west of Black Weir Pier, as far as a line running south from Ballynacourty Pier the seabed is predominantly soft mud and is devoid of oysters.

The seabed at Stations III and IV is predominantly dead 'coral' (*Lithothamnion* sp.) and shell overlying mud.

(g) *Ostrea edulis* can survive in water temperatures ranging from $0^{o}C$ to $25^{o}C$ but its distribution is limited by its temperature requirements during the breeding season when temperatures in excess of approximately $15^{o}C$ are necessary for successful propagation. Growth occurs when the water temperature exceeds approximately $10^{o}C$ (see Chapter V).

Weekly average surface water temperatures at the oyster bed are presented for 1970, 1971 and the first half of 1972, in Figure 3b. No water temperature records are available for the Clarinbridge estuary for 1968 or 1969. Therefore, water temperatures recorded at the University

FIGURE 3a.

WEEKLY AVERAGE SURFACE WATER TEMPERATURE
AT CARNA AND THE CLARINBRIDGE PUBLIC OYSTER FISHERY
IN 1968 AND 1969

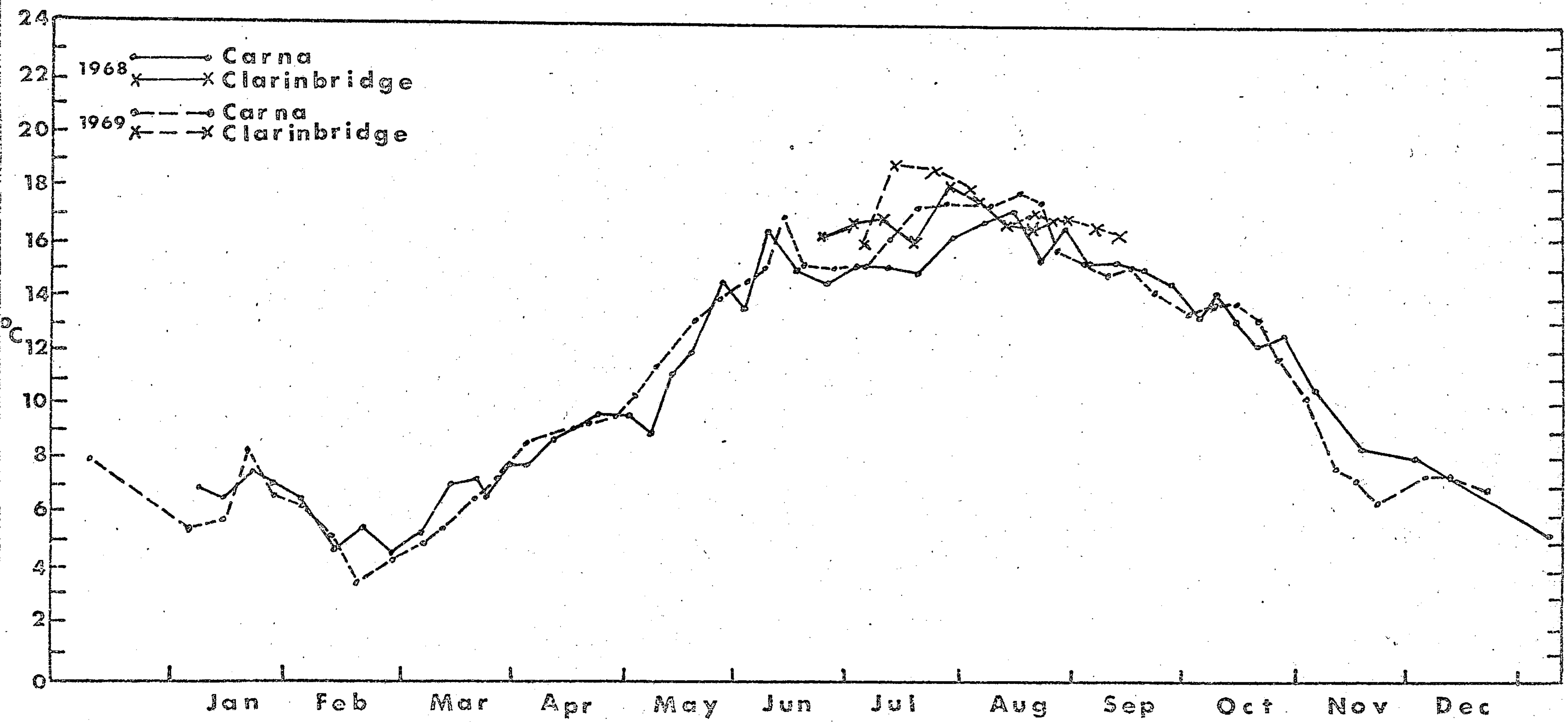
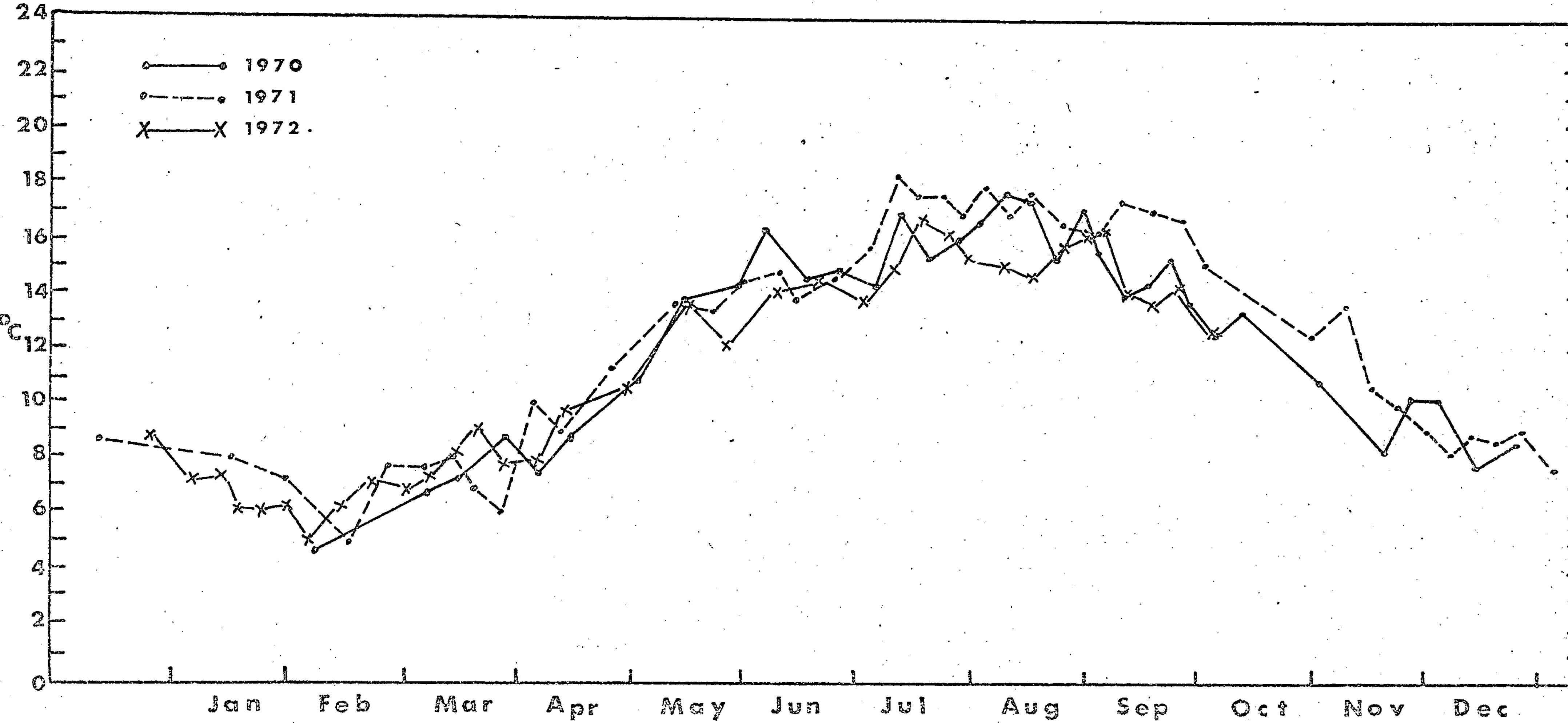


FIGURE 3b.

WEEKLY AVERAGE SURFACE WATER TEMPERATURE
AT THE CLARINBRIDGE PUBLIC OYSTER FISHERY
IN 1970, 1971 AND 1972



College Galway Zoology Department Field Station at Carna on the north-west coast of Galway Bay are presented in Figure 3a; with summer temperatures at Clarinbridge superimposed. The Carna records are very similar to those collected at Clarinbridge and will suffice for the general arguments presented later. More detailed temperature readings for the summers of 1968 to 1971 are presented in Chapter IV.

Water temperatures recorded at Stations II, III, and IV (Map 6) have not been presented because they did not differ greatly from those recorded over the oyster bed. Occasionally lower temperatures (a maximum difference of 0.5°C) were recorded at Stations III and IV and at Stations I and II, but the reverse was also found to be the case at times.

The surface water temperatures presented in Figures 3a and 3b generally present an accurate picture of temperatures throughout the water column because thermal stratification rarely occured in the shallow waters of the Clarinbridge estuary. Differences of up to 0.5°C between surface and bottom water layers were recorded over the oyster bed between early June and the end of September. However, differential heating generally affected only the top few inches of water column, the remainder being uniform in temperature throughout. Occasionally differences of 1°C between surface and bottom waters were recorded in calm conditions at Station III but these were rarely maintained for more than a day or two. In winter, discharges of cold fresh water reduced the surface water temperature slightly below that of the more saline bottom waters (a maximum difference of 0.8°C) but such conditions rarely prevailed for any length of time. Rough seas usually caused thorough mixing.

Lowest water temperatures at Clarinbridge occurred consistently in February - the minimum being 3.0°C in February 1969. Highest temperatures occurred in July and August when maxima of over 19°C were recorded (1969). However, temperatures exceeding 18°C were uncommon during the investigation period, and the sustained maxima recorded were generally between 17°C and 18°C. In contrast, at Tralee, where different hydrographic conditions prevail, temperatures exceeding 20°C have been recorded regularly in recent years (Duggan, pers. comm.) as they have also in Essex (Waugh, 1957), in the Oosterschelde (Korringa, 1941) and at Morbihan (Marteil, 1960).

(h) Salinity

Ostrea edulis is euryhaline and can thrive in salinities of 23‰ to 35‰ (Yonge, 1960). However, as Yonge points out, it is difficult to give definite figures relating to the salinity tolerance of *O. edulis* in natural conditions because salinity changes very rapidly and also very widely due to the ebb and flow of tides and the seaward movement of river water.

Considerable salinity fluctuations were recorded at Clarinbridge. Only summer salinities remained fairly constant between approximately 28‰ and 32‰ and these are presented in Figure 9 in Chapter IV.

In the winter and spring, when fresh-water discharge was at its maximum, surface water salinity fell as low as 9‰ at low spring tides, but generally it rose again to approximately 24‰ on the flooding tide, while corresponding bottom water salinities usually returned to approximately 27 ‰.

Between mid-May and early November, salinities generally exceeded 25 ‰, reaching maxima exceeding 34 ‰ occasionally in July and August. In the summer, rainfall and fresh water had little or no effect on salinity at Clarinbridge which appeared to be slightly higher than that recorded in Essex (Waugh, 1957a) and the Oosterschelde (Korringa, 1941).

As with water temperature, salinity changed little with depth over the oyster bed, except during periods of high freshwater discharge. Similarly, fluctuations accompanying the tidal cycle were minimal for most of the year (see Table 26 in Chapter IV).

(j) Turbidity

Excessive turbidity can reduce the pumping rate of adult oysters (Loosanoff and Tommers, 1948, cited by Korringa, 1952) and reduce their feeding efficiency. It can also reduce the survival of larvae and influence phytoplankton production by reducing light penetration.

Turbidity assessments were made at Clarinbridge during the summer of 1968, using a Secchi disc. However, no meaningful results could be obtained in the vicinity of the oyster bed because the disc rarely disappeared in the shallow water. It was assumed, therefore, that excessive turbidity would not be a serious threat to oyster production and the assessments were discontinued.

(k) pH and oxygen concentration

pH was measured only once (May 18th, 1972) at the oyster bed when a value of 8.4 was recorded. This is slightly higher than has been generally recorded in Essex (Knight-Jones, 1952; Waugh, 1957a) and at Morbihan (Marteil, 1960) where values of 7.0 to 8.3 were more common. A high pH, however, would be expected in such a predominantly limestone area, and also at a time of high phytoplankton production. (Phytoplankton blooms may occur as late as mid-May in some inshore areas of Galway Bay - Dooley, pers. comm.).

The pH of the Kilcolgan River in a non-tidal reach two miles east of the oyster bed was 7.7 on the same day. Flanagan and Toner (1972) reported pH values of 7.8 to 8.1 at the same station (Kilcolgan bridge) in 1971.

Oxygen concentrations were not measured during these investigations. However, no obvious signs of oyster mortality due to oxygen depletion were observed.

4. Meteorlogical Observations

(a) Air Temperature

The weekly average mean air temperatures* recorded at University College Galway from 1968 to 1972 are presented in Figures 4a and 4b. February was consistently the coldest month, when temperatures dropped below zero on several occasions. The highest mean air temperatures were recorded in June, July and August, the highest reading being 20.2°C in early June, 1970.

*weekly averages of daily mean air temperatures.

FIGURE 4a.

WEEKLY AVERAGE MEAN AIR TEMPERATURE
AT GALWAY
IN 1968 AND 1969

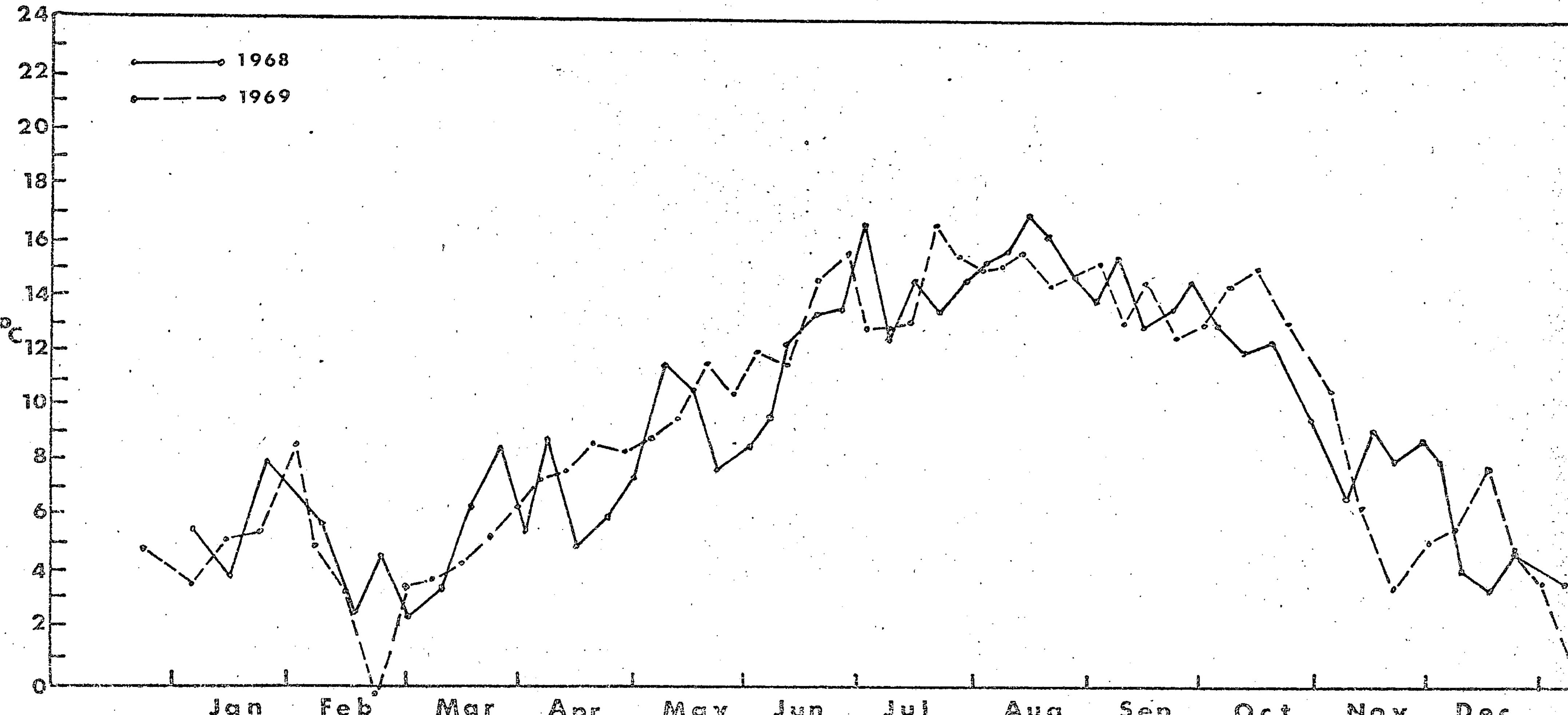
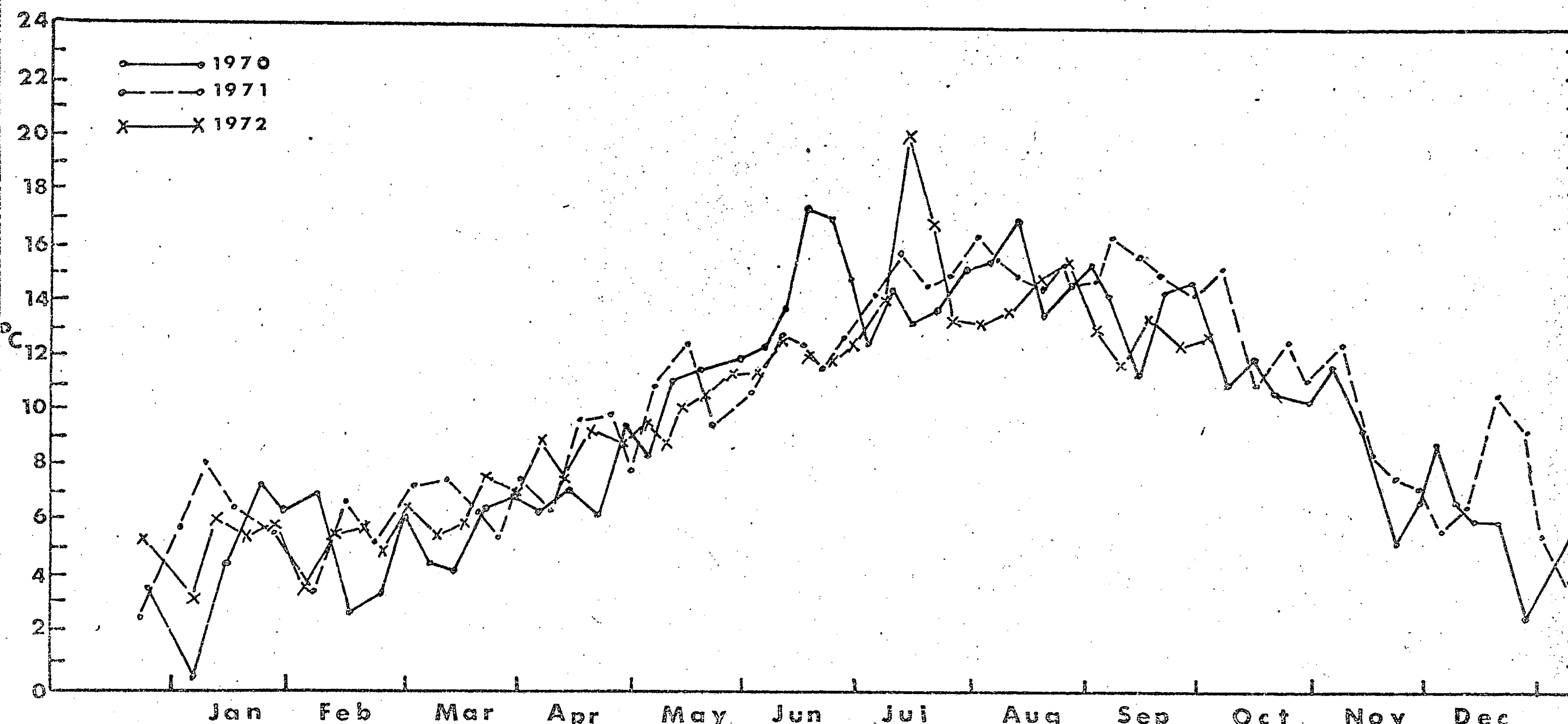


FIGURE 4b.

WEEKLY AVERAGE MEAN AIR TEMPERATURE
AT GALWAY
IN 1970, 1971 AND 1972



(b) Sunshine

Weekly sunshine totals (hours) for 1969 to 1972 are presented in Figure 5. There was little difference between the total number of hours of sunshine recorded in Galway in 1969, 1970, and 1971 -- approximately 1,350 hours each year. However, there was more sunshine during the summer (May to August inclusive of 1969 (713.8 hours) than in 1970 (627.9) or 1971 (665.7 hours) and this was reflected in the higher water temperatures recorded in that year.

(c) Cloud

No estimates of cloud cover were made during these investigations. Presumably cloud amounts were approximately inversely proportional to the amounts of sunshine recorded.

(d) Rainfall

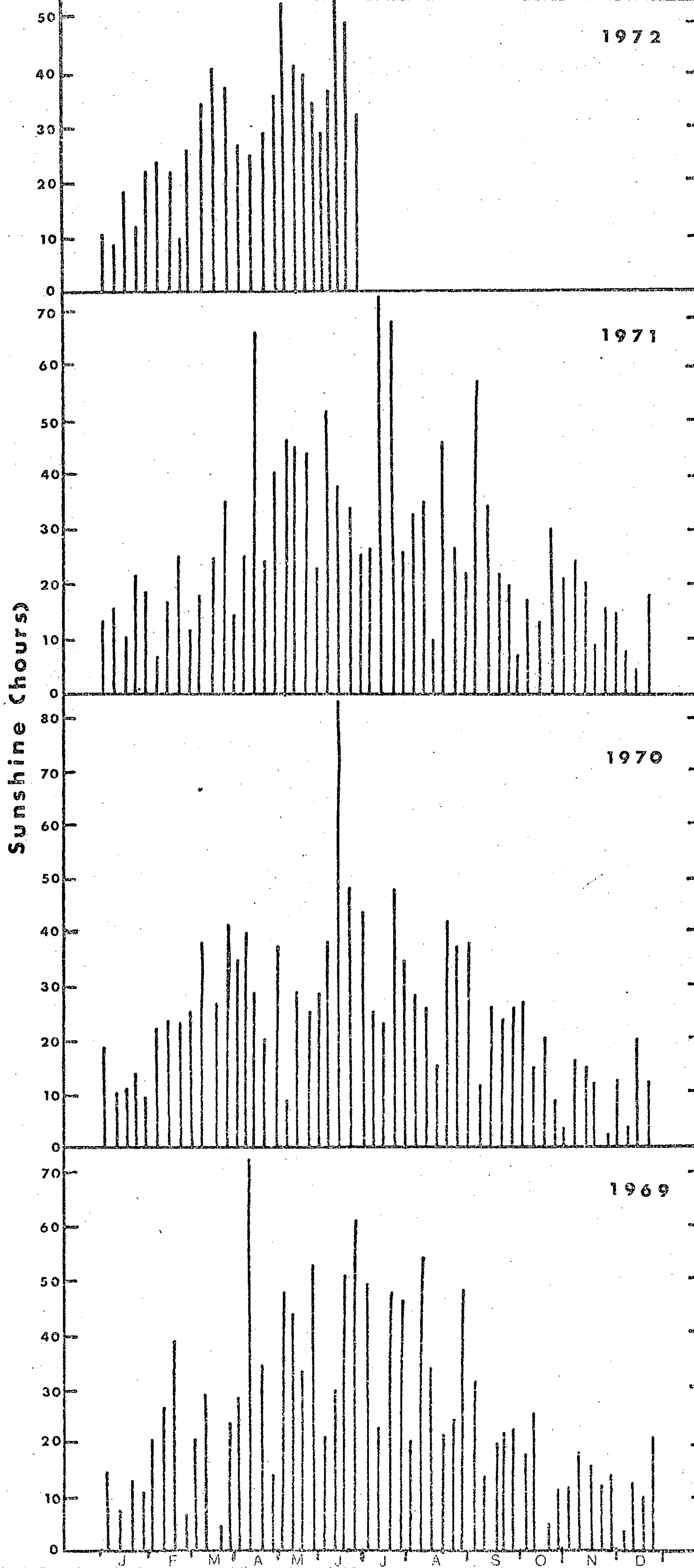
Weekly rainfall totals (mm) for 1969 are presented in Figure 6. The total annual rainfall was 993.8 m.m. in 1969, 1,102 mm in 1970 and 839.6 mm in 1971 (the driest year in Galway for 33 years -- Gaffney, pers. comm.). These figures are considerably greater than those recorded in Essex -- 430 m.m. to 575 m.m. per annum (Waugh, 1957a) and at Morbihan -- 710 m.m. per annum (Marteil, 1960). Rainfall was distributed fairly evenly throughout each year with no consistently wet or dry periods except perhaps for a relatively dry period from February to May.

(e) Wind

Wind records for 1970 and 1971 are presented in Figure 7, as the weekly averages of the daily wind amounts recorded at Galway and are given in Km/hr. The monthly

FIGURE 5.

WEEKLY SUNSHINE AT GALWAY FROM 1969 TO 1972



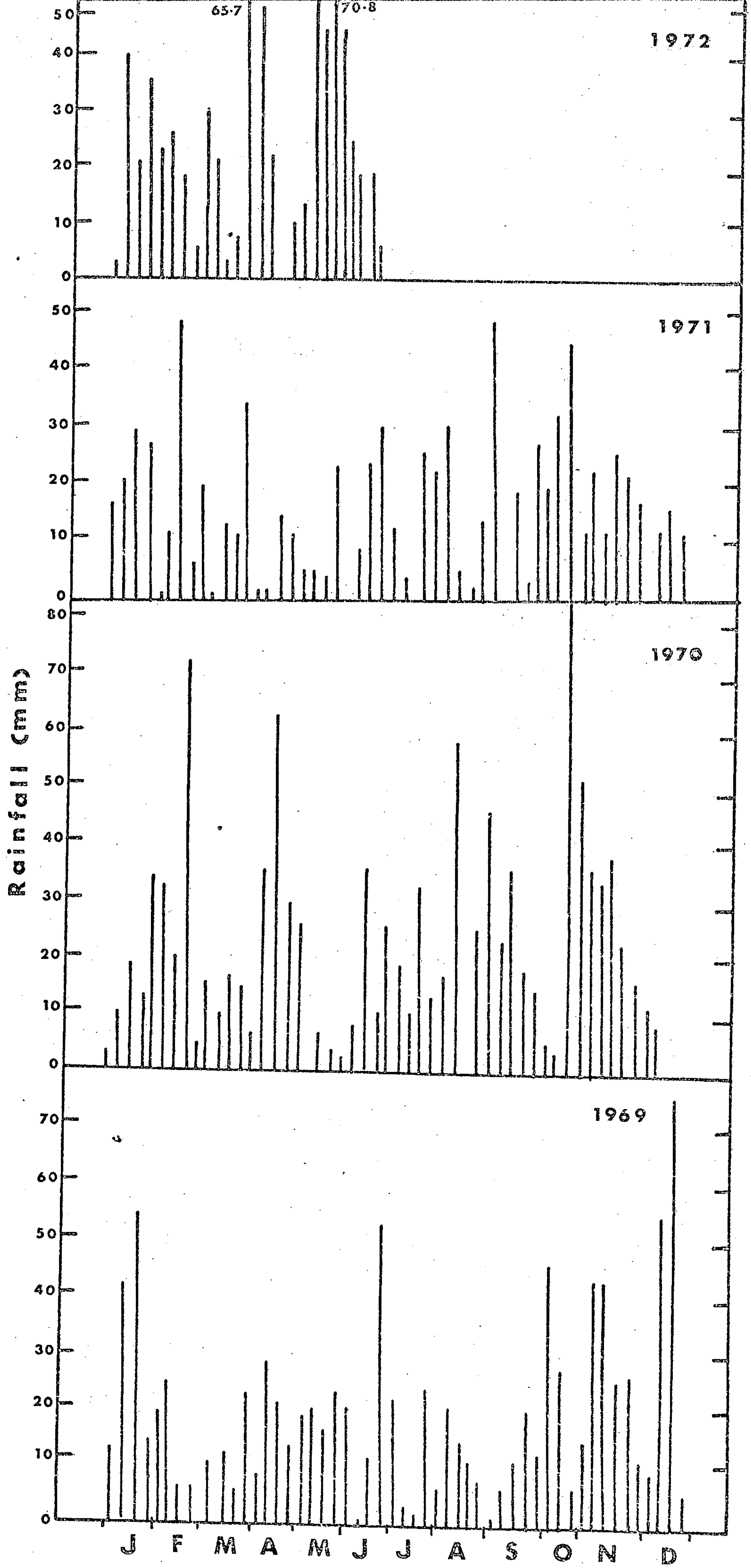
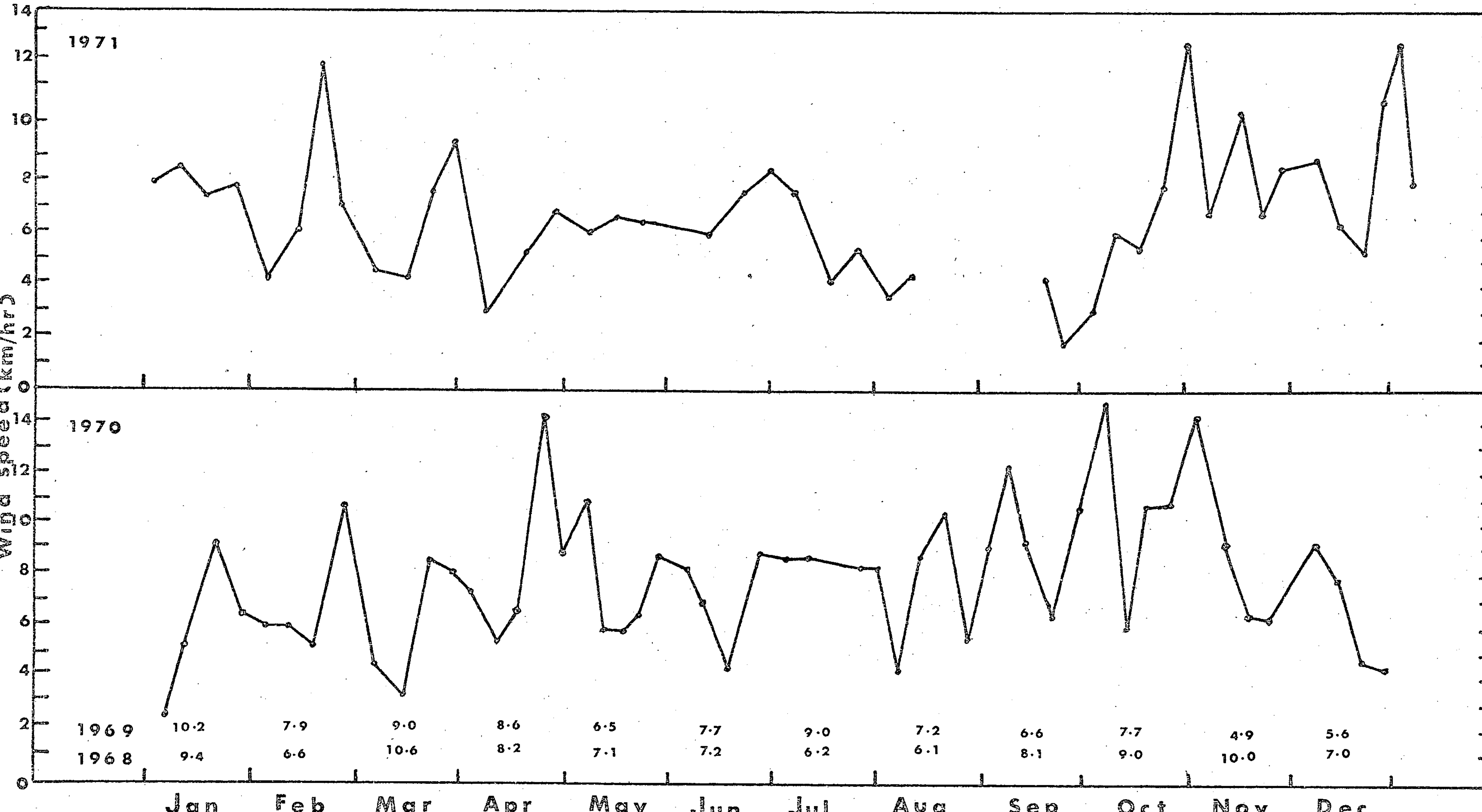


FIGURE 6.
WEEKLY RAINFALL AT GALWAY FROM 1969 TO 1972

FIGURE 7. WEEKLY AVERAGE WINDSPEED AT GALWAY IN 1970 AND 1971



averages for 1968 and 1969 are also given on Figure 7. Wind was distributed fairly evenly throughout the year but the prevailing wind varied from season to season. Westerly and south-westerly winds were commonest from approximately May to December, whilst easterly winds were more common during the early months of the year (Gaffney, pers. comm.). Table 14 below gives the average number of days when winds were recorded from various directions at Galway in 1968 and 1969.

TABLE 14

WIND DIRECTION FREQUENCY AT GALWAY IN 1968 AND 1969

Direction	N	NE	E	SE	S	SW	W	NW
No. Days	36	30	45	19	55	39	58	52

Source: Annual Weather Reports, Meteorlogical Services Dublin.

The figures above show that most wind comes from a westerly direction, and this is generally mild and damp. The predominant cold winds from the east in the winter presumably have a cooling effect on the water over the oyster bed. In addition, the winds tend to push the tide out further than usual on ebb tides, thereby extending the time of exposure of some parts of the oyster bed and increasing the possibility of frost damage to oysters.

(f) Frost and snow

Ground frosts occurred mainly between early November and the end of April, although they were also recorded occasionally in the summer. Table 15 below presents the number of days when ground frost was recorded at Galway between January 1968 and March 1971.

TABLE 15

THE FREQUENCY OF GROUND FROSTS AT GALWAY - 1968 TO 1971

	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
1968	11	25	13	12	11	0	0	0	1	0	10	19	102
1969	16	24	15	15	18	2	0	0	1	2	22	19	134
1970	22	20	16	15	0	0	0	0	0	1	14	17	105
1971	18	12	14	-	-	0	0	0	0	-	-	-	---

Snowfall was negligible in the vicinity of Clarinbridge during these investigations.

(5) Food

It was not possible to study the food of oysters at Clarinbridge during these investigations but it is recognised that the nature and abundance of available food organisms is of critical importance to the survival and development of oyster stocks in Galway Bay and further mention of the subject will be made in Chapter VII.

(6) Pollution

At the present time the Clarinbridge oyster bed is free from all types of pollution. However, as Galway becomes industrialized and urbanisation extends towards nearby rural areas, such as Clarinbridge, the likelihood of pollution from domestic and industrial sources reaching the oyster bed will increase. At the present time the author is cooperating with the local authorities in a pollution monitoring programme in Galway Bay. The results of the survey to date and the implications of the results as regards oyster husbandry will be discussed in more detail in Chapter VI.

Flanagan and Toner (1972) reported that the Kilcolgan River "shows some slight deterioration in the vicinity of Loughrea and also below Kilcolgan but otherwise it is satisfactory." They gave it a quality grading of 4 at Kilcolgan Bridge, which according to their scale (5 to 1 = good to bad) is fair, and indicates that "little interference with the beneficial use of the river" was observed.

CHAPTER IV

LARVAE PRODUCTION AND SPAT SETTLEMENT

IV. LARVAE PRODUCTION AND SPAT SETTLEMENT

A thriving oyster industry is based on an abundant supply of seed oysters, which are often referred to as 'spat'. To date, most oyster fisheries around the world have had to rely on natural spat settlement to replenish their stocks and any determined efforts to increase oyster production have been based on a detailed knowledge of larvae production and spat settlement in the natural environment (Spärck, 1924; Orton, 1937a; Korringa, 1941; Knight-Jones, 1952; Marteil, 1960; Loosanoff and Engle, 1940; Cahn, 1950; Bacon, 1970; Cranfield, 1968).

The following chapter describes the investigations into larvae production and spat settlement carried out by the author at the Clarinbridge Public Oyster Fishery from 1968 to 1971. The data collected at Clarinbridge could not be as detailed as those produced by some of the authors mentioned above because of the relatively short period of the investigation and the fact that this author had limited technical assistance available to him. However, the results, which compare favourably with those of other workers, provide some basic information which will be valuable in the development of the fishery.

A detailed description of the anatomy and physiology of the reproductive organs of Ostrea edulis is outside the scope of this work. However, a brief account of the breeding cycle will be presented as a prelude to the following sections.

Ostrea edulis, like all other species of the genus, is larviparous and incubatory. On release from the gonads the eggs are retained in the mantle cavity of the female. Here they are fertilized by sperm carried in water currents from a nearby male. The resulting embryos develop into fully shelled larvae during an incubation period of 6 to 20 days, depending on the temperature, and are then released into the sea. Female oysters (*O.edulis*) can produce from 100,000 to 1,500,000 larvae, depending on their size (Walne, 1964).

After a pelagic phase of 10 to 20 days, depending on the water temperature, the mature larvae move towards the seabed where, after a period of exploratory crawling (Cole and Knight-Jones, 1939), they attach to a suitable substrate where they will remain for the rest of their lives, unless disturbed.

In contrast, species of the genus *Crassostrea* are oviparous and non-incubatory. The sex products of both sexes are discharged directly into the sea (in several separate swarms) where fertilisation and development occurs. The direct discharge of eggs and spermatozoa into the sea greatly increases the potential mortality rate of newly formed embryos, but this hazard is effectively counteracted by the vast numbers of eggs produced -- up to 70 million in one spawning of *C.virginica* (Loosanoff, 1965).

Ostrea edulis is a protandric hermaphrodite - spat first become sexually mature as males and then change relatively slowly into functional females. A few days after the eggs have been discharged the females revert quickly to the male state and so on alternately through life. Sex changes occur more rapidly in warmer conditions with the result that in a warm summer it is possible that all the sexually mature oysters in a population will function as females at least once during the breeding season.

Natural spat production is now being complemented by artificial hatchery production which will be mentioned again in Chapter VII.

A. The Production, Abundance and Distribution of Oyster Larvae

1. Sampling and Examination of Plankton

Quantitative plankton samples were collected by pumping 150 litres of water, from a depth of approximately 2 metres, through a No.25 (200 mesh per inch) bolting silk. The pump employed was a standard, manually-operated fire pump requiring 480 single strokes to pump 150 litres. This calibration was checked periodically and only negligible differences in the volume of water sampled were detected, even though the pump was operated by different personnel under a variety of conditions.

After pumping the silks were transferred to glass sample jars and immersed in a 5% formalin solution in seawater. They were then transported in this preservative to the laboratory for examination. A disadvantage of treating a sample with formalin at this stage is that the eyed larvae tend to lose their pigment if they are preserved too long, rendering them less easily recognisable (Key, pers. comm.). Countering this disadvantage is the fact that if formalin is not employed some larvae may be destroyed by predators in the sample if it is not examined immediately. Also, it is necessary to treat the sample with formalin to fix the larvae before examination. In order to minimise the adverse effects of formalin on larvae the samples were examined within four hours of collection.

Three samples were taken each week at four stations (Map 6) during the 1968 study period, two per week at each of stations I to III in 1969 and two per week at all four stations in 1970 and 1971. Sampling was carried out as near to high tide as possible on all occasions. This was done for three reasons: (a) to avoid variations which might occur over the tidal cycle; (b) because it has been suggested by various authors (see later) that major releases of larvae occur at high water; and (c) because the water level over the oyster bed was often too shallow to allow sampling at low water. However, periodically samples were taken at other stages in the tidal cycle to compare the numbers of larvae present in specific areas with those taken regularly at high water.

In the laboratory each sample was treated in the following way:

All the material attached to the silk was washed into a bowl. The solution remaining in the sample jar was decanted into the bowl and the jar was rinsed with fresh water so that any remaining material could be washed into the bowl.

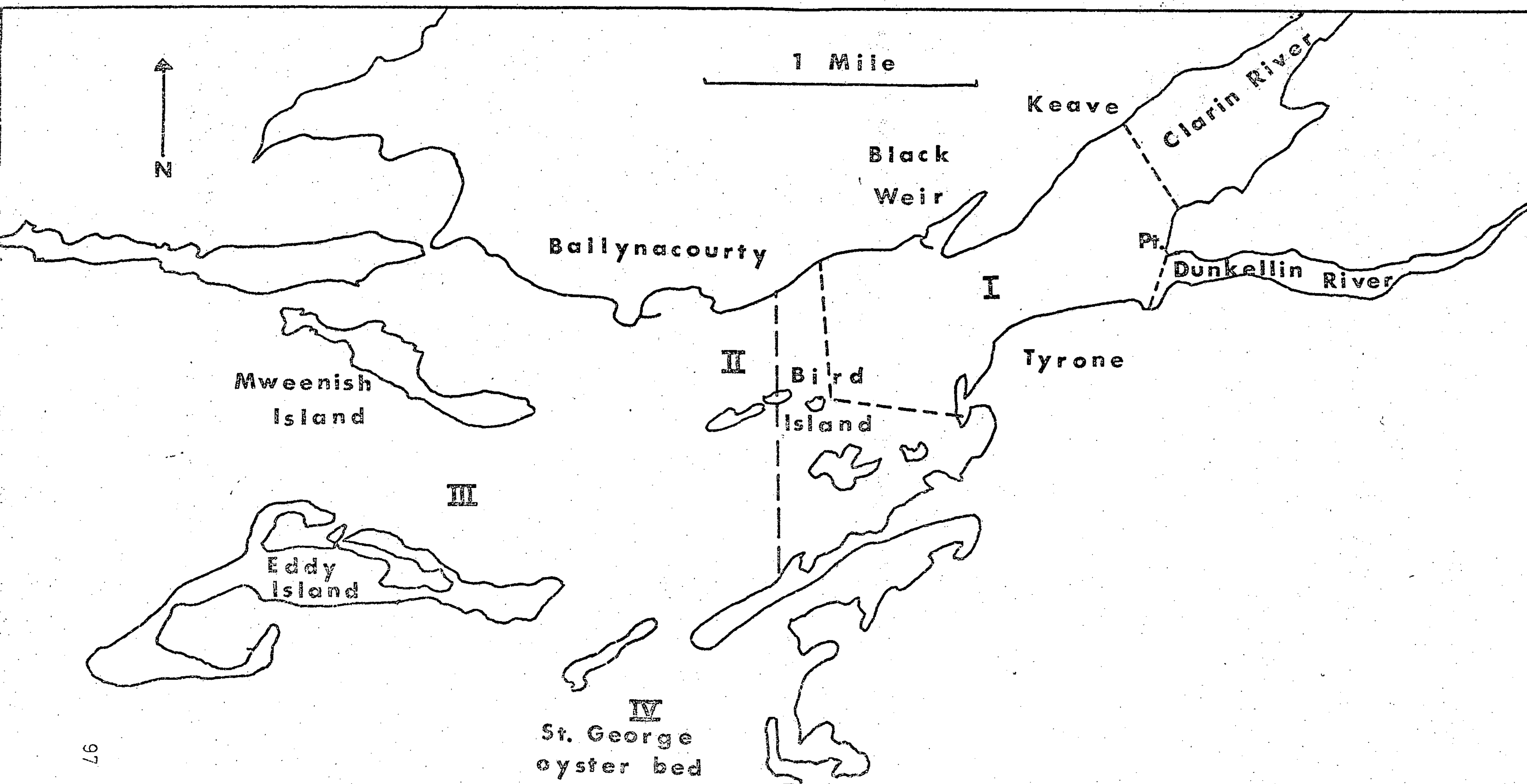
The sample was then 'centrifuged' with a glass rod until all the heavy particles, including all oyster larvae, were concentrated in the centre of the bowl where they were allowed to settle to the bottom. This material was then pipetted onto a squared slide for examination under a medium-powered binocular microscope. Complete counts of larvae were made by examining all the material which had settled in the centre of the bowl. The larvae were classified as "immature" or "eyed" and in 1971 samples were also measured to the nearest 10 μ (0.01mm).

2. Gonad Development, Spawning and the Release of Larvae

Orton (1937a) suggested that gonad development in *Ostrea edulis* begins when the water temperature exceeds about 10°C and that the time necessary for the maturation of eggs is probably largely dependent on temperature conditions. Since oyster growth generally starts at 10°C-12°C in Wales (Walne, 1958) and at about 10°C in Ireland (see later) it will be assumed, and in the absence of contrary information, that sexual development commences at a minimum water temperature of 10°C in natural conditions.

Histological investigations of gonad development of Clarinbridge oysters were not made by the author. However, the time required for initial gonad maturation has been back-calculated from the estimated dates of first spawning in 1968 to 1971. Assuming that gonad development started at 10°C, these periods varied between maxima of approximately 16 days in 1968, 32 days in 1969, 37 days in 1970 and 46 days in 1971.

MAP 6. PLANKTON SAMPLING STATIONS



The initial spawning occurred at water temperatures of 13.8°C to 14.3°C. A provisional timetable for gonad maturation and first spawning is presented in Table 16, below.

TABLE 16

TIMETABLE FOR GONAD MATURATION AND FIRST SPAWNING
OF CLARINBRIDGE OYSTERS

	1968	1969	1970	1971
10°C reached *	May 15th.	April 27th.	April 24th.	April 15th.
Estimated first spawning	May 31st.	May 29th.	May 30th.	May 30th
Estimated maximum period of gonad maturation	16 days	32 days	37 days	46 days
Water temperature at first spawning	14.3°C	14.3°C	14.2°C	13.8°C

*Weekly average surface water temperature.

Orton (1937a) assumed that the minimum water temperature at which O.edulis can spawn -- that is, release the sex products from the gonads -- is a physiological constant of 15°C to 16°C. He showed that the breeding season was longer in areas where the water temperature exceeded 15°C for a greater part of the year (e.g., in Italy) than in cooler areas such as Britain. However, Korringa (1956a) produced evidence that suggests that there are different physiological races of O.edulis, each with a different breeding temperature requirements. For example, Norwegian oysters, living in cold waters at the northern limit to the species range, spawn only at water temperatures above 20°C. These high temperatures result from the 'greenhouse-effect' of a layer of fresh-water overlying the breeding waters. In contrast, in the warm waters of Spain, spawning may occur at temperatures as low as 13°C to 14°C. Waugh (1957a) noted that in Essex rivers, mass spawning was generally associated with a rise in water temperature above 16°C, but he pointed out, as had Korringa (1956), that the attainment of such a temperature did not automatically trigger off spawning, indicating the importance of favourable conditions during the period of gonad maturation. Marteil (1960) agreed that spawning does not appear to be governed by a threshold temperature but added that temperature may initiate spawning in sexually mature oysters.

The date of first spawning at Clarinbridge has been back-calculated from the date of the first appearance of larvae in the water using an approximate value for the incubation period (the time during which the fertilised eggs develop within the mantle cavity of the female), based on estimates made by other workers. Erdmann (1934, cited by Korringa, 1941) estimated incubation periods of 18 days at 13°C to 14°C, 14 days at 17°C to 18°C and 6 to 8 days at 23°C. Cole (1939), however, deduced from tank and field experiments, an incubatory period of 10 days at 16°C to 20°C. Since the water temperature at Clarinbridge was approximately 14°C during the period prior to the first release of larvae in each year of the study it is suggested that the initial incubation period was about 18 days. This estimate tends to be substantiated by the uniformity of the water temperature 18 days before the first release of larvae (Table 17).

TABLE 17.

POSSIBLE DATES OF INITIAL SPAWNING AT THE CLARINBRIDGE PUBLIC OYSTER FISHERY

	1968		1969		1970		1971	
Date of First Larvae Release	June 18th		June 15th		June 17th		June 17th	
Possible Incubation Periods (days)	Date	T(^{o}C)	Date	T(^{o}C)	Date	T(^{o}C)	Date	T(^{o}C)
10	June 8th.	14.3	June 5th.	14.8	June 7th.	16.0	June 7th.	14.3
14	June 4th.	14.0	June 1st.	14.6	June 3rd.	16.7	June 3rd.	14.8
18	May 31st.	14.3	May 29th.	14.3	May 30th.	14.5	May 31st.	13.8
22	May 27th.	13.3	May 25th.	14.1	May 26th.	14.5	May 27th.	13.3

Table 17. also shows that, irrespective of the length of the incubation period, initial spawning occurred at a lower temperature at Clarinbridge than had been recorded in England (Waugh, 1957a), France (Marteil, 1960) or in Holland, where twenty years of records showed that spawning did not occur until a threshold of $15^{\circ}C$ to $16^{\circ}C$ had been surpassed (Korringa, 1956). However, it must be added that major spawnings at Clarinbridge must have occurred at water temperatures of at least $15^{\circ}C$ (see Figures 8 and 9). Nevertheless, this evidence suggests that Clarinbridge oysters may be physiologically different from other European stocks. These differences may be of genetic origin since work currently being carried out in the Department of Zoology at University College, Galway (Wilkins and Mathers, pers. comm.), suggests the existence of genetically based biochemical differences between Clarinbridge, Tralee Bay and Norwegian oysters. Furthermore, the possibility that Clarinbridge oysters are physiologically distinct from other European stocks is increased by the fact that there have been only small scale transplantations of foreign oysters into the area in recent times. In contrast, massive transplantations of foreign oysters have been made between Holland, France and Britain during the past century and the resulting replacement and mixing of stocks has led to a similarity in breeding temperature requirements in these three countries (Korringa, 1956a).

According to Korringa (1956a) spawning often ceases before the water temperature drops to the critical level. In Holland he observed that larvae production had usually ceased by the beginning of September, even when the temperature remained above 18°C. At Clarinbridge, larvae production also appeared to diminish before the critical temperature was reached.

During the incubation the fertilised eggs develop in the mantle cavity of the female oyster. The embryos first appear as a milky mass, developing into the recognisable shelled larvae after 5 or 6 days (Spärck, 1924). At this stage the oyster is described as white-sick. Samples of larvae from white-sick oysters examined at Clarinbridge measured 130µ to 160µ across their widest diameter parallel to the hinge. As they grow the larvae develop grey pigmentation and then the parent oyster is termed grey-sick. Larvae at this stage were 170µ to 180µ long. Finally, the larvae turn dark-grey and generally measured 190µ to 200µ long. The attainment of this 'black-sick' stage indicates that larvae release is imminent.

Several workers, including Orton (1937a) and Korringa (1941), determined the percentage of oysters carrying larvae at various times during the breeding season in an attempt to predict large larvae releases. Orton (1937a) found a maximum of 25.5% carrying larvae in the River Blackwater on June 15th, 1927. This figure comprised 12.9% black-sick, 3.6% grey-sick, 2.9% white-sick and 6.1% premature white-sick (i.e., presumably embryos prior to shell development). However, he did not relate these observations to subsequent counts of planktonic larvae, but he did mention that since the pelagic phase should last about 14 days, heavy spat settlement could be expected about two weeks after the appearance of large numbers of black-sick oysters.

In a series of samples of 50 oysters taken in the Oosterschelde in 1939, Korringa (1941) recorded a maximum of 42% carrying larvae -- 20% were white-sick and 22% were black-sick. Although the samples contained only 50 oysters he assumed that the figures he obtained did not deviate too much from the percentages for the total population because subsequent larvae releases followed a similar pattern of fluctuations. From these data and his records of newly released larvae he estimated that more than 100% of the oyster population had spawned during 1933 and 1939, thus indicating that some oysters must have functioned as females for a second time during those seasons.

In 1963, samples of 50 Clarinbridge oysters were examined for breeding condition at weekly intervals. The results are given in Table 18, below.

TABLE 18.

PERCENTAGE FREQUENCY OCCURRENCE OF WHITE-SICK, GREY-SICK AND BLACK-SICK OYSTERS AT CLARINBRIDGE IN 1968

Date	White-Sick	Grey-Sick	Black-Sick	Total
June 27th	0	0	8	8
July 3rd	2	0	0	2
July 10th	0	4	6	10
July 17th	8	4	4	16
July 24th	0	0	12	12
July 31st	10	4	4	18
August 7th	0	0	4	4
August 14th	16	0	0	16
August 21st	10	2	0	12
Total			38	

These results did not tally with the subsequent larvae releases (see Figure 8a). The peak of 12% black-sick oysters recorded on July 24th was followed by an increase in larvae release on July 25th, but the peak larvae release in mid-August could not be ascribed to the high percentage of white-sick oysters recorded on August 14th because insufficient time had elapsed for these larvae to mature. Insufficient data were available on spat settlement in 1968 to determine the relationship between the percentage of oysters carrying larvae and the intensity of subsequent spat settlement.

By totalling the percentages of black-sick oysters it was possible to estimate approximately the proportion of the population which functioned as females during the study period. Orton (1937a) stated that the black-sick stage lasted about three days. Therefore, since samples were taken at Clarinbridge at weekly intervals it is possible that about twice as many oysters as shown in Table 18 functioned as females during the 1968 study period -- that is, about 75%. However, the complete breeding season could not be monitored in 1968. so it is possible, in the light of the foregoing evidence, that, in effect, at least 100% of the population functioned as females during the season.

Spawning Periodicity

Considerable interest has been shown by a number of workers (e.g., Spärck, 1929; Orton, 1937a; Cole, 1939; Korringa, 1941 and 1957; Knight-Jones, 1952; and Waugh, 1957a) in the spawning periodicity of O. edulis, that is, the relationship between spawning intensity and the lunar or tidal cycle.

Orton once thought that peak spawning coincided with full and new moons. However, he observed this phenomenon only once and in a later paper (1937b, cited by Korringa, 1941) admitted that such lunar periodicity had not been confirmed. Cole and Spärck, observing spawning in tanks in Conway and Limfjord respectively, did not observe lunar periodicity in the breeding cycle of their oysters, suggesting that another factor must be responsible for the apparent periodicity noted by Orton. Korringa (1941), however, found that large numbers of recently liberated larvae usually appeared about ten days after a full moon or a new moon. Since he estimated the incubation period to be about 8 days, this indicated spawning maxima about 2 days after the full and new moons, that is, at spring tides. Knight-Jones (1952) observed peaks of spawning in Essex rivers at spring tides and also throughout the rest of the tidal cycle. Waugh (1957a), continuing Knight-Jones' observations, found that spawning occurred at spring tides only in a slight majority of cases, though it did occur more frequently when tides were increasing to springs rather than decreasing to neaps.

No direct attempt has been made to clarify this situation in the present study because a knowledge of the exact time of peak spawning is only marginally important in oyster fishery management. However, in 1968, when larvae production was high and plankton samples were taken three times a week, peak numbers of recently released larvae occurred 7 or 8 days after new or full moons (Figure 8a). In 1969, peak releases also occurred approximately 10 days after new and full moons. In 1970 the largest releases occurred 10 days after new and full moons.

Larvae production in 1971 was too small to warrant critical analysis for spawning periodicity.

The peak releases during 1968, 1969, and 1970 all occurred during periods when the water temperature exceeded 16°C. Thus, if the incubation period was about 10 days at this temperature as suggested by Cole (1939), peak spawnings would have occurred at Clarinbridge mainly on increasing spring tides, as was also observed by Waugh in Essex. However, larvae were also released, each season, throughout the tidal cycle indicating that spring tides alone are not the ultimate factor determining spawning periodicity.

Finally, though spawning periodicity has not generally been confirmed, it could, as Knight-Jones (1952) pointed out, provide advantages for larvae survival. If peak spawning occurs at spring tides and larvae release occurs at neap tides most larvae will spend their first few days of independent life in condititons of minimum currents, turbulence and turbidity.

The Release of Larvae Throughout the Tidal Cycle

Knight-Jones (1952) concluded from observations in the Rivers Crouch and Roach, Essex, that oyster larvae were released in all weathers and at varying salinities. However, the releases did not occur with uniform frequency throughout the tidal cycle, the major releases taking place at high water. Waugh (1957a) found less convincing evidence of high water releases and noted one large release at low water in the River Crouch.

In the present study most plankton samples were taken at high water, for reasons stated earlier. However, in 1971 samples were collected throughout the tidal cycle at Stations I, III, and IV. Larvae production was poor in 1971 and the low counts make interpretation of the results difficult. Nevertheless, the numbers and size frequency distribution of larvae collected at half-hourly intervals have been presented in Tables 19 and 20.

Tables 19 and 20 show that there were definite increases in the numbers of newly released larvae during the period of high water at Station I, which is situated directly over the centre of the oyster bed. Table 19 shows that by far the highest percentage of newly released larvae (200μ) occurred at high water on both flooding and ebbing tides. An increase in the numbers of larger larvae (220μ and above) at Station I on a flooding tide suggests that these had been transported back to the oyster bed from an area close to Station III where they had grown during their period of dispersal.

At Station III, about two miles west of the oyster bed, a more even distribution of oyster larvae was observed throughout the tidal cycle (Table 19) as would be expected at a site remote from the main part of the oyster bed (Korringa, 1941: Marteil, 1960). The percentage of size-frequency distribution of larvae collected at Station III shows that the highest percentages of newly released larvae occurred at low water. Since there are no adult oysters in the vicinity of the station this suggests that they had been released at high water and then transported westwards by the ebbing tide.

Thus, it can be tentatively concluded that the major releases of larvae occurred near the high water at the Clarinbridge oyster bed during the period of investigation.

TABLE 19. NUMBERS OF LARVAE RECORDED THROUGHOUT THE TIDAL CYCLE AT STATIONS I, III AND IV IN 1971

Station	I	I	III	IV
Date	July 8th	July 13th	July 9th	July 10th
Sample				
	Low Water	High Water	Low Water	Low Water
1	–	253	28	Foul
2	32	250	139	5
3	15	290	53	3
4	26	167	93	1
5	48	Foul	80	3
6	Foul	18	71	0
7	35	51	Foul	2
8	30	Foul	90	2
9	77	55	48	0
10	77	19	60	6
11	85	Foul	Foul	4
12	140	12	60	10
	High Water	Low Water	High Water	High Water

TABLE 20. PERCENTAGE SIZE-FREQUENCY DISTRIBUTION OF OYSTER LARVAE AT VARIOUS STAGES OF THE TIDAL CYCLE IN 1971.

Station	I				I		III			
Date	July 8th				July 13th		July 9th			
Sample	2	5	9	II	I		1	4	7	10
Size μ	Low Water			High Water	High Water	Low Water	Low Water			High Water
190	6.7	8.0	3.3	8.3	1.7		10.0	–	3.7	6.7
200	50.0	48.0	36.7	70.0	71.7		60.0	46.7	55.6	33.3
210	26.7	32.0	30.0	13.3	16.7		20.0	30.0	25.9	36.7
220	16.6	12.0	16.7	5.0	8.3		10.0	13.3	7.4	16.7
230			3.3	1.7	–			–	–	3.3
240				1.7	–			–	3.7	–
250					1.7			3.3		3.3
260								6.7		

Note: No further samples measured at Station I on July 13th or at Station IV on July 10th -- samples too small

Water Temperature and Larvae Release

Generally, it has been found (Korringa, 1956a) that there is no correlation between water temperature and the onset of larvae release. Provided conditions are adequate for gonad development, spawning and incubation, larvae will be released automatically, irrespective of temperature and weather conditions. This seems to be borne out by results recorded at Clarinbridge, where larvae were first observed at temperatures of 16°C (1968), 17.2°C (1969), 14.8°C (1970) and 14.0°C (1971), and also by laboratory experiments in which embryos, obtained from a River Blackwater oyster and spawned at 20°C, were reared successfully through to metamorphosis at 14°C to 15°C without undue mortality (Walne, 1965).

Size and Growth of Pelagic Larvae

The size of larvae at release and their growth during the pelagic phase have far reaching effects on the subsequent growth and survival of spat and on their recruitment into the adult population. Waugh (1957a) showed that the size of larvae at maturity (i.e., when they become eyed) depends largely on their size at release (See Table 21). This suggests that relatively large larvae, released early in the breeding season, will have the advantage of size and a longer growing period over later released larvae during their first season (from settlement to approximately early December at Clarinbridge). Waugh also observed, as had Korringa (1941) and Knight-Jones (1952), that larvae were apparently smaller towards the end of the breeding season, probably, it was suggested, because they were the offspring of oysters which had been functioning as males earlier in the summer and as a consequence these parent oysters had depleted food resources. Marteil (1960) drew the same conclusions from his observations, but emphasised the possible role of temperature in the phenomenon. He also found that at release the larvae at Morbihan were generally smaller than those recorded in more northerly waters.

Table 21 presents comparative data on the size of larvae at various stages of development as determined by Erdmann (1934, from Korringa, 1941), Cole (1939), Knight-Jones (1952), Marteil (1960) and the author. It shows that in all but the warmer waters of Morbihan and the rearing tanks at Conway, larvae ranged in size from 130μ to 200μ. The data presented in the table also highlight the apparent reduction in size of larvae in the latter part of the breeding season in most of the areas studied, but a corresponding decrease in the size of mature larvae towards the end of the breeding season is not demonstrated so convincingly.

The release of small larvae and the subsequent settlement of smaller eyed larvae, particularly towards the end of the breeding season, would appear to be a disadvantage to the survival and perpetuation of a species. Waugh (1957a) speculated on the possibility that small larvae will produce stunted though mature oysters which may produce further generations of stunted oysters. Since such oysters are of no commercial value they are allowed to remain on the oyster bed and, therefore, have a greater chance to contribute to larvae production. Such a proposition seems unlikely in the light of recent biochemical investigations at University College Galway (Mathers, pers. comm.)

TABLE 21

THE SIZE OF LARVAE AT VARIOUS STAGES OF DEVELOPMENT

Authority	Size of Larvae - μ					
	In Mantle Cavity	At Release		Eyed		
		Early Season	Late Season	Early Season	Late Season	Spat
Erdmann		200-210	160-180			
Cole		160-200	160-200	270-280	270-280	290-310
Korringa	160-200	200	175-185	260-300	260-300	
Knight-Jones		180-200	180-200	260-300	230-240	
Waugh		190-200	160-180	250-270	240-250	
Marteil		160-190	160	260	240-280	
Whilde	130-200	180-200	170-200	260-330	260-330	280-330

which indicates no genetically based differences between normal and apparently stunted Clarinbridge oysters.

Nevertheless, earlier spat which may arise from larger larvae, as a result of lower temperatures at the beginning of the season (see later), have a better chance to grow well during their first year and are, therefore, in greater demand from the oyster farmer who places correspondingly less value on late season spat. In the warmer waters of Morbihan where spat have a longer growing season after the termination of the breeding season the production of small larvae may be less significant to annual production than in areas such as Galway Bay where late spat may not attain a size of more than 1.5mm by their first winter.

Thus, it can be surmised that the success of the 1969 spatfall at Clarinbridge (see later) hinged not only on the production of large numbers of larvae, but also on the fact that the major releases came early in the season.

Regular measurements of pelagic larvae were made only during 1971 when a minimum of thirty larvae, randomly selected from each sample, were measured. The percentage size frequency of larvae at each station is given in Tables 22a,b,c and d. Unexpectedly, fewer large larvae (240µ and over) were caught at Station III than at Stations I or II, although the largest eyed larvae observed in 1971 were taken at this station. Generally, fewest larvae were caught at Station IV in 1971 but these showed a wider size frequency distribution. Apparently hydrographic conditions (which are discussed in detail in the section on spat settlement) in this

TABLE 22(a)

PERCENTAGE SIZE FREQUENCY DISTRIBUTION OF LARVAE DURING THE 1971 BREEDING SEASON

STATION I

Size μ Date	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	No.Larvae in Sample
21/6	-	-	11.5	38.5	47.0	3.0	-	-	-	-	-	-	-	-	-	-	120
24/6	-	-	6.7	60.0	13.3	20.0	-	-	-	-	-	-	-	-	-	-	50
28/6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
1/7	-	-	2.9	29.4	29.4	32.4	5.8	-	-	-	-	-	-	-	-	-	76
5/7	-	-	1.7	16.7	25.0	33.3	8.3	3.3	8.3	-	1.7	1.7	-	-	-	-	244
8/7	-	-	8.3	70.0	13.3	5.0	1.7	1.7	-	-	-	-	-	-	-	-	140
12/7	-	-	5.0	61.7	26.7	5.0	1.7	-	-	-	-	-	-	-	-	-	85
16/7	-	3.3	10.0	33.3	30.0	20.0	3.3	-	-	-	-	-	-	-	-	-	70
19/7	-	6.7	20.0	48.3	16.7	3.3	1.7	1.7	1.7	-	-	-	-	-	-	-	610
23/7	-	2.9	5.7	45.7	20.0	18.6	2.9	2.9	1.4	-	-	-	-	-	-	-	156
27/7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	36
29/7	-	11.7	38.3	28.3	11.7	5.0	1.7	-	-	-	1.7	1.7	-	-	-	-	173
3/8	-	3.3	13.3	38.3	15.0	16.7	8.3	1.7	1.7	-	1.7	-	-	-	-	-	102
5/8	-	13.3	26.7	23.3	11.7	11.7	6.7	3.3	3.3	-	-	-	-	-	-	-	85
12/8	-	3.3	16.7	40.0	10.0	20.0	3.3	6.7	-	-	-	-	-	-	-	-	35
16/8	-	30.0	26.7	43.3	-	-	-	-	-	-	-	-	-	-	-	-	40
19/8	-	3.3	25.0	61.7	1.7	5.0	1.7	-	-	1.7	-	-	-	-	-	-	95
27/8	5.0	20.0	40.0	35.0	-	-	-	-	-	-	-	-	-	-	-	-	188
2/9	3.3	20.0	40.0	13.3	3.3	-	-	-	-	-	-	-	-	-	-	-	50
8/9	-	10.0	10.0	30.0	3.0	13.3	6.7	-	-	-	-	-	-	-	-	-	45
14/9*	-	-	3.5	25.0	18.3	20.0	8.3	8.3	5.0	1.7	5.0	1.7	1.7	-	-	-	30
17.9	-	-	3.3	43.3	6.7	10.0	13.3	3.3	16.7	3.3	-	-	-	-	-	-	50
20/9*	-	6.0	10.0	31.0	7.0	11.0	10.0	5.0	12.0	4.0	2.0	1.0	1.0	-	-	-	126
23/9*	-	8.0	20.0	46.7	10.7	4.0	2.7	4.0	-	-	1.3	2.7	-	-	-	-	80
27/9*	-	-	36.7	43.3	13.3	-	-	-	3.3	-	-	-	3.3	-	-	-	93
30/9*	-	1.7	11.7	36.3	20.0	15.0	2.3	1.7	1.7	1.7	1.7	-	1.7	1.7	-	1.7	113
Size μ	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	

*Results for all stations combined.

TABLE 22(b)

PERCENTAGE SIZE FREQUENCY DISTRIBUTION OF LARVAE DURING THE 1971 BREEDING SEASON

STATION II

Size μ / Date	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	No. Larvae In Sample
21/6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
24/6	-	-	10.0	20.0	40.0	20.0	10.0	-	-	-	-	-	-	-	-	-	18
28/6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	40
1/7	-	-	-	23.5	58.8	5.9	5.9	-	5.9	-	-	-	-	-	-	-	32
5/7	-	-	-	18.3	20.0	28.3	8.3	8.3	11.7	1.7	3.3	-	-	-	-	-	194
8/7	-	-	-	31.3	43.8	6.3	-	-	6.3	6.3	-	6.3	-	-	-	-	40
12/7	-	-	4.0	66.0	24.0	6.0	-	-	-	-	-	-	-	-	-	-	70
16/7	-	-	10.0	33.3	26,7	26.7	6.7	-	-	-	-	-	-	-	-	-	92
19/7	-	3.3	16.7	50.0	20.0	3.3	-	3.3	3.3	-	-	-	-	-	-	-	70
23/7	-	-	10.0	50.0	16.7	20.0	-	-	-	3.3	-	-	-	-	-	-	30
27/7	-	1.7	25.0	33.3	20.0	10.0	6.7	-	1.7	1.7	-	-	-	-	-	-	80
29/7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20
3/8	-	5.0	15.0	35.0	20.0	15.0	1.7	3.3	-	1.7	-	3.3	-	-	-	-	157
5/8	-	1.7	8.3	28.3	25.0	11.7	8.3	6.7	8.3	5.0	1.7	-	-	-	-	-	97
12/8	-	-	20.0	33.3	13.3	16.7	6.7	3.3	3.3	-	-	3.3	-	-	-	-	33
16/8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
19/8	-	10.0	56.7	20.0	3.3	6.7	3.3	-	-	-	-	-	-	-	-	-	50
27/8	-	25.0	50.0	21.7	1.7	1.7	-	-	-	-	-	-	-	-	-	-	251
2/9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15
8/9	-	3.3	30.0	30.0	16.7	6.7	3.3	6.7	3.3	-	-	-	-	-	-	-	35
14/9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22
17/9	-	-	6.7	20.0	6.7	13.3	13.3	10.0	16.7	3.3	6.7	-	3.3	-	-	-	75
20/9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	42
23/9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	33
27/9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
30/9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16
Size μ	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	

TABLE 22(c)

PERCENTAGE SIZE FREQUENCY DISTRIBUTION OF LARVAE DURING THE 1971 BREEDING SEASON

STATION III

Size μ / Date	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	No. Larvae In Sample
21/6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11
24/6		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9
28/6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
1/7	-	-	4.8	33.3	47.6	14.3	-	-	-	-	-	-	-	-	-	-	34
5/7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20
8/7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
12/7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15
16/7	-	-	3.3	33.3	30.0	33.3	-	-	-	-	-	-	-	-	-	-	75
19/7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28
23/7	-	6.7	16.7	50.0	13.3	10.0	-	-	3.3	-	-	-	-	-	-	-	30
27/7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20
29/7	-	10.0	16.7	53.3	10.0	3.3	3.3	-	3.3	-	-	-	-	-	-	-	32
3/8	-	1.7	15.0	45.0	16.7	8.3	6.7	5.0	-	-	-	-	-	-	-	-	150
5/8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15
12/8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18
16/8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
19/8	-	30.0	33.3	23.3	6.7	3.3	-	3.3	-	-	-	-	-	-	-	-	65
27/8	-	13.3	13.3	46.7	3.3	3.3	-	-	-	-	-	-	-	-	-	-	65
2/9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8/9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14/9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	73
17/9	-	10.0	10.0	16.7	20.0	16.7	10.0	3.3	6.7	3.3	3.3	-	-	-	-	-	40
20/9		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	54
23/9	-	1.7	11.7	36.7	20.0	15.0	2.3	1.7	1.7	1.7	1.7	-	1.7	1.7	-	1.7	30
27/9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13
30/9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Size μ	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	

TABLE 22(d)

PERCENTAGE SIZE FREQUENCY DISTRIBUTION OF LARVAE DURING THE 1971 BREEDING SEASON

STATION IV

Size μ Date	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	No. Larvae In Sample
21/6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
24/6	–	–	16.7	41.7	33.6	8.3	–	–	–	–	–	–	–	–	–	–	16
28/6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	15
1/7	–	–	–	7.1	57.1	21.4	14.3	–	–	–	–	–	–	–	–	–	35
5/7	–	–	1.7	25.0	21.7	25.0	11.7	3.3	6.7	1.7	–	3.3	–	–	–	–	85
8/7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	25
12/7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	35
16/7	–	–	3.3	33.3	33.3	26.7	–	–	3.3	–	–	–	–	–	–	–	105
19/7	–	–	–	13.3	20.0	26.7	16.7	10.0	10.0	3.3	–	–	–	–	–	–	45
23/7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	25
27/7	–	–	13.3	40.0	10.0	16.7	3.3	3.3	3.3	3.3	3.3	3.3	–	–	–	–	50
29/7	–	–	16.7	26.7	13.3	13.3	6.7	6.7	10.0	3.3	3.3	–	–	–	–	–	36
3/8	–	–	16.7	30.0	20.0	16.7	3.3	3.3	–	–	–	3.3	3.3	3.3	–	–	35
5/8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	15
12/8	–	3.5	16.7	30.0	20.0	16.7	3.3	3.3	3.3	–	–	–	3.3	–	–	–	40
16/8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6
19/8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	12
27/8	6.7	16.7	43.3	23.3	6.7	3.3	–	–	–	–	–	–	–	–	–	–	68
2/9	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5
8/9	–	10.0	13.3	46.6	13.3	6.7	3.3	3.3	–	3.3	–	–	–	–	–	–	42
14/9	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	15
17/9	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	27
20/9	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6
23/9	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
27/9	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
30/9	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	12
Size μ	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	

area cause the concentration and retention of larvae which leads to the presence of a larger proportion of mature larvae than elsewhere, at least in years of low larvae production such as 1970 and 1971 (see Table 19).

Table 23 presents the size frequency distribution of all the larvae taken at Stations I to IV in 1971. The figures in brackets are the accumulated percentages of the numbers of larvae exceeding a particular size. For example, 17.6% of the larvae counted at Station I grew to and exceeded 210µ. These figures show clearly that a larger proportion of mature larvae occurred in samples taken at Station IV than at any other station in 1971.

The larger proportion of larvae measuring from 170µ to 210µ inclusive (I,32.4%; II,73.6%; III,80.9%; IV,63.9%) and the small percentage of eyed larvae recorded (see later) suggests that larvae growth was poor in 1971. The possible reasons for this poor growth will be discussed in a later section.

A superficial inspection of Tables 22a to 22d suggests that the size of newly released larvae declined towards the end of the breeding season -- an interpretation in keeping with those of Korringa (1941), Knight-Jones (1952), Waugh (1957a) and Marteil (1960). However, Walne (1964), from a further analysis of Waugh's data, could not provide clear evidence of a diminution in the size of larvae towards the end of the season. Using his method of comparing the percentage number of larvae which had grown through 10µ size groups in the first half (June 21st to August 5th) and the second half

TABLE 23.

PERCENTAGE SIZE FREQUENCY DISTRIBUTION OF LARVAE AT STATIONS I TO IV IN 1971

Size class (μ)

Station	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	Total
I	0.5	6.9	15.5	43.2	16.3	10.0	3.6	1.3	1.8	0.3	0.3	0.2	0.1	0	0	0	100.0
	(99.5)	(92.6)	(77.1)	(33.9)	(17.6)	(7.6)	(4.0)	(2.7)	(0.9)	(0.6)	(0.3)	(0.1)	(0)	(0)	(0)	(0)	
II	0	3.1	16.3	32.0	22.2	12.3	4.6	2.6	3.8	1.4	0.7	0.8	0.2	0	0	0	100.0
	(100.0)	(96.9)	(80.6)	(48.6)	(26.4)	(14.1)	(9.5)	(6.9)	(3.1)	(1.7)	(1.0)	(0.2)	(0)	(0)	(0)	(0)	
III	0	8.0	14.7	37.3	20.8	11.7	2.2	1.7	1.9	0.4	0.4	0	0	0	0.2	0.2	100.0
	(100.0)	(92.0)	(77.3)	(39.5)	(18.7)	(7.0)	(4.8)	(3.1)	(1.2)	(0.8)	(0.4)	(0.4)	(0.4)	(0.4)	(0.2)	(0)	
IV	0.6	2.5	12.6	30.0	23.2	15.1	6.1	2.8	3.6	1.2	0.6	0.8	0.6	0.3	0	0	100.0
	(99.4)	(96.9)	(84.3)	(54.3)	(31.1)	(16.0)	(9.9)	(7.1)	(3.5)	(2.3)	(1.7)	(0.9)	(0.3)	(0)	(0)	(0)	

Total number of larvae counted:

I	1,848
II	1,611
III	900
IV	1,200

(August 6th to September 23rd) of the breeding season the following results are obtained for samples taken at Station I (Table 24).

TABLE 24.

THE PERCENTAGE OF LARVAE WHICH HAD GROWN THROUGH SUCCESSIVE 10μ SIZE GROUPS DURING THE 1971 BREEDING SEASON - EARLY AND LATE

Size-class (μ)	170	180	190	200
June-July	100	96.8	87.2	48.4
August-September	99.2	89.7	77.2	32.6

These results suggest a definite diminution in the size of larvae during the second half of the breeding season. However, a more detailed analysis of the daily records (Table 25) suggests that the former conclusion is erroneous. It will be noted that at the beginning of the season most larvae exceeded 190μ at release. Larvae less than 190μ in diameter were first recorded on July 16th after a period of warmer weather during which the water temperature exceeded 13.0°C for much of the time. While these conditions prevailed larvae measuring 130μ were common. A small number of larvae measuring 170μ in diameter were recorded at Stations I and IV between August 26th and September 3rd after a period during which the water temperature did not exceed 17.5°C. Subsequently, the minimum size of newly released larvae increased, with only a small proportion not exceeding 180μ.

These results, based only on one season's sampling, tend to confirm Marteil's observations that the size of larvae,

TABLE 25.

THE PERCENTAGE OF LARVAE WHICH HAD GROWN THROUGH SUCCESSIVE 10 μ SIZE-GROUPS DURING THE 1971 BREEDING SEASON AT CLARINBRIDGE

	Station I				All Stations			
Date	170	180	190	200	170	180	190	200
21/6	100	100	89.0	50.5	100	100	89.5	50.0
24/6	100	100	92.3	32.3	100	100	91.1	46.5
28/6	-	-	-	-	100	100	86.1	13.9
1/7	100	100	97.1	67.7	100	100	97.7	72.1
5/7	100	100	98.3	78.9	100	100	98.9	78.9
8/7	100	100	92.7	22.7	100	100	93.0	33.7
12/7	100	100	95.0	33.3	100	100	95.4	31.8
16/7	100	96.7	86.7	63.4	100	99.2	92.5	60.0
19/7	100	93.3	73.3	25.0	100	95.8	81.6	25.0
23/7	100	97.1	91.1	45.7	100	96.9	87.7	40.0
27/7	100	98.3	73.3	40.0	100	98.9	77.8	42.2
29/7	100	88.3	50.0	21.7	100	91.7	64.2	30.0
3/8	100	96.7	83.4	45.1	100	97.1	82.3	44.2
5/8	100	86.7	60.0	36.7	100	92.5	75.0	46.7
12/8	100	96.7	80.0	40.0	100	97.8	80.0	45.6
16/8	100	70.0	43.3	0	100	70.0	43.3	0
19/8	100	96.7	71.7	53.7	100	88.3	53.3	11.6
27/8	95.0	75.0	35.0	0	97.2	77.2	34.4	3.8
2/9	96.7	76.7	56.7	16.7	91.7	76.7	56.7	16.2
8/9	100	90.0	80.0	50.0	100	92.2	74.4	38.8
14/9	100	100	96.5	71.5	100	100	96.5	71.5
17/9	100	100	96.7	56.4	100	96.7	90.0	56.4
20/9	100	94.0	84.0	53.0	100	94.0	84.0	53.0
23/9	100	92.0	72.0	26.3	100	92.0	72.0	26.3
26/9	-	-	-	-	100	100	63.3	20.0
30/9	-	-	-	-	100	98.3	86.6	49.9

at least at the beginning of the season, diminishes with an increase in temperature. However, they do not clearly confirm Waugh's contention that newly released larvae are generally smaller towards the end of the season, because while smaller larvae (170μ) did appear in the plankton during the latter half of the season they were recorded on only two occasions and subsequently the newly released larvae were dominated by 190μ and 200μ size groups, as was the case at the beginning of the season. Further, it was after the disappearance of the 170μ group that some of the largest percentages of mature larvae were recorded. Thus, it must be concluded that at Clarinbridge the size of the newly released larvae can vary throughout the breeding season and does not necessarily diminish as the season progresses.

Eyed Larvae and the Length of the Pelagic Phase.

When pelagic larvae reach maturity and are about to metamorphose and settle they develop a pair of black pigment spots which are readily visible through each transpatent valve. The first appearance of large numbers of these 'eyed' larvae in the plankton indicates that spat settlement is imminent and will occur if favourable environmental conditions prevail. Eyed larvae vary in size, as is shown in Table 21, those in Clarinbridge ranging from 260μ to 330μ in diameter.

In 1968 and 1969, eyed larvae first appeared in the plankton during the first week of July. In 1970, however, no eyed larvae were observed until August 4th, five days after the first oyster spat had been recorded. In 1971, the first eyed larvae and first spat were both observed on July 27th. If it is assumed that the first eyed larvae appeared at the end of July in 1970, then it will be seen that the potential onset of spat settlement in 1970 and 1971 was about three weeks later than in 1968 and 1969. However, in 1968, the first spat was recorded on July 15th and in 1969, on July 24th, only two weeks and one week, respectively, in advance of the first settlement in 1970 and 1971. This suggests that in spite of the earlier maturation of larvae in 1968 and 1969, many eyed larvae must have perished because conditions were unsuitable for settlement in the first half of July.

On average, the highest counts of eyed larvae amounted to 3.3% of the total number of larvae in any sample. Usually, however, they accounted for 1% or less. In general these percentages are similar to those recorded by Knight-Jones (1952) and Waugh (1957a), although in exceptional years they found that up to 8% of the larvae population reached the eyed stage on some occasions.

Too few eyed larvae were recorded at Clarinbridge to confirm Waugh's observation that small larvae at release give rise to small eyed larvae.

Several of the researchers mentioned previously have shown that the pelagic phase of the oyster's life cycle lasts from 6 to 14 days, depending on the water temperature. Korringa (1941) observed a planktonic phase of 6 days at 22°C to 23°C and about 14 days at 16°C to 17°C in the Oosterschelde. Waugh (1957a) recorded a planktonic life span of 7 days at 21°C and 8 days at 20°C in the River Crouch, Essex. Cole (1939) reported a period of 10 days at 16°C to 20°C which, he suggested, would be increased by only one day at temperatures $2^{\circ}C$ to $3^{\circ}C$ less. Waugh believed that this was an under-estimate of the effects of lower temperatures, but agrees with Cole that the abundance of food probably plays an important complementary, but subsidiary role to temperature in the development of larvae, thereby justifying, to a certain extent, Cole's assertions which were based largely on observations of well-fed, tank-reared oysters.

In 1968, the first major release of larvae occurred at Clarinbridge on June 28th and the first spat were noted on July 15th, suggesting a pelagic phase of up to 17 days at $16^{\circ}C$ to $17^{\circ}C$. The few eyed larvae in the plankton during the intervening period probably perished or settled undetected. In 1969 the major release of larvae occurred on July 14th and this was followed by a major settlement on July 28th. This indicated a pelagic phase of 14 days at $18^{\circ}C$ to $19^{\circ}C$. The first major release in 1970 was on July 28th and this was followed by a heavy settlement on August 17th -- a pelagic phase of 20 days at $16.5^{\circ}C$ to $18^{\circ}C$. One major release of larvae occurred in 1971 on July 19th. On August 3rd there was a heavy settlement at Station IV, indicating a possible pelagic phase of approximately 15 days at a temperature of about $17^{\circ}C$.

These estimates compare favourably with those of Korringa (1941) but deviate from the results obtained by Cole in his tank experiments. However, as Waugh pointed out, Cole's oysters were probably better fed and therefore matured quicker than larvae in a natural environment.

It can be concluded from these estimates that in the summer conditions prevailing at Clarinbridge (water temperature ranging from 16°C to 19°C) the pelagic phase of oysters lasts from 14 to 17 days and possibly slightly longer if food is scarce, as may have been the case in 1970 when the condition of oysters (see later) and mussels (Murray, pers. comm.) at Clarinbridge was relatively poor during the early part of the breeding season.

Numbers and Distribution of Larvae

The numbers of larvae recorded from 150L plankton samples at Stations I, II, III and IV (Map 6) at regular intervals during 1968, 1970 and 1971 are given in Figures 8a to 8d and 8h to 8o. Only three stations were sampled regularly in 1969 and these results are given in Figures 8e to 8g.

Table 26 presents the average number of immature and eyed larvae recorded at each station during the period (July 9th to August 23rd) of greatest larvae production common to each breeding season investigated.

Figures 8a to 8o and Table 26 show clearly that, at high water, there were always more larvae over the oyster bed (Station I) than in adjacent areas. Numbers at Station IV, however, were often higher than at Station III, in the main estuary, possibly, as mentioned earlier, because it received larvae from sources other than the main oyster bed.

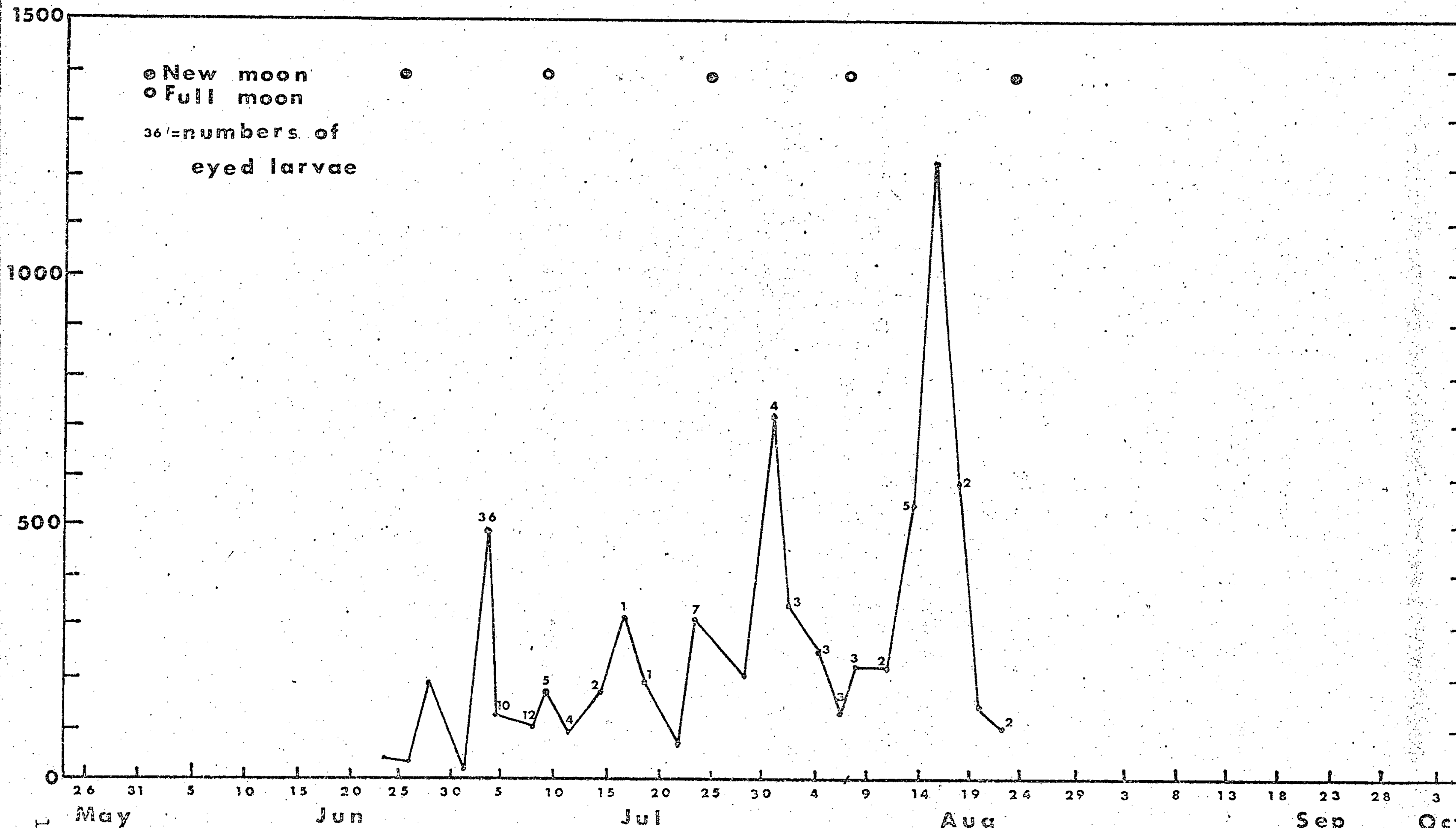
Larvae production was highest in 1969 (Figures 8e to 8g) when an average of 359 larvae per sample was recorded (Table 26). (It was felt that it was safe to pool the

TABLE 26

AVERAGE NUMBERS OF LARVAE RECORDED BETWEEN JULY 9TH AND AUGUST 23RD IN THE YEARS 1968 TO 1971

Station	Average Number of Larvae per 150L Sample											
	1968			1969			1970			1971		
	Immature	Eyed	No. Samples	Immature	Eyed	No. Samples	Immature	Eyed	No. Samples	Immature	Eyed	No. Samples
I	431	2.9	20	670	12.5	13	121	1.8	11	113	0.3	13
II	315	2.8	20	290	8.2	13	109	1.0	11	70	0.6	14
III	151	2.5	20	117	3.9	13	74	0.8	11	41	0.4	14
IV	171	2.4	20	--Not sampled --			95	2.9	7	36	0.7	14
Total	1,068	10.6		1,077	24.6		299	6.5		260	2.0	
Mean	267	2.7		359	8.2		75	1.6		65	0.5	
Ratio	99	1.0		44	1.0		47	1.0		130	1.0	

FIGURE 8a. NUMBERS OF LARVAE PER 150 L. SAMPLE RECORDED AT STATION I IN 1968



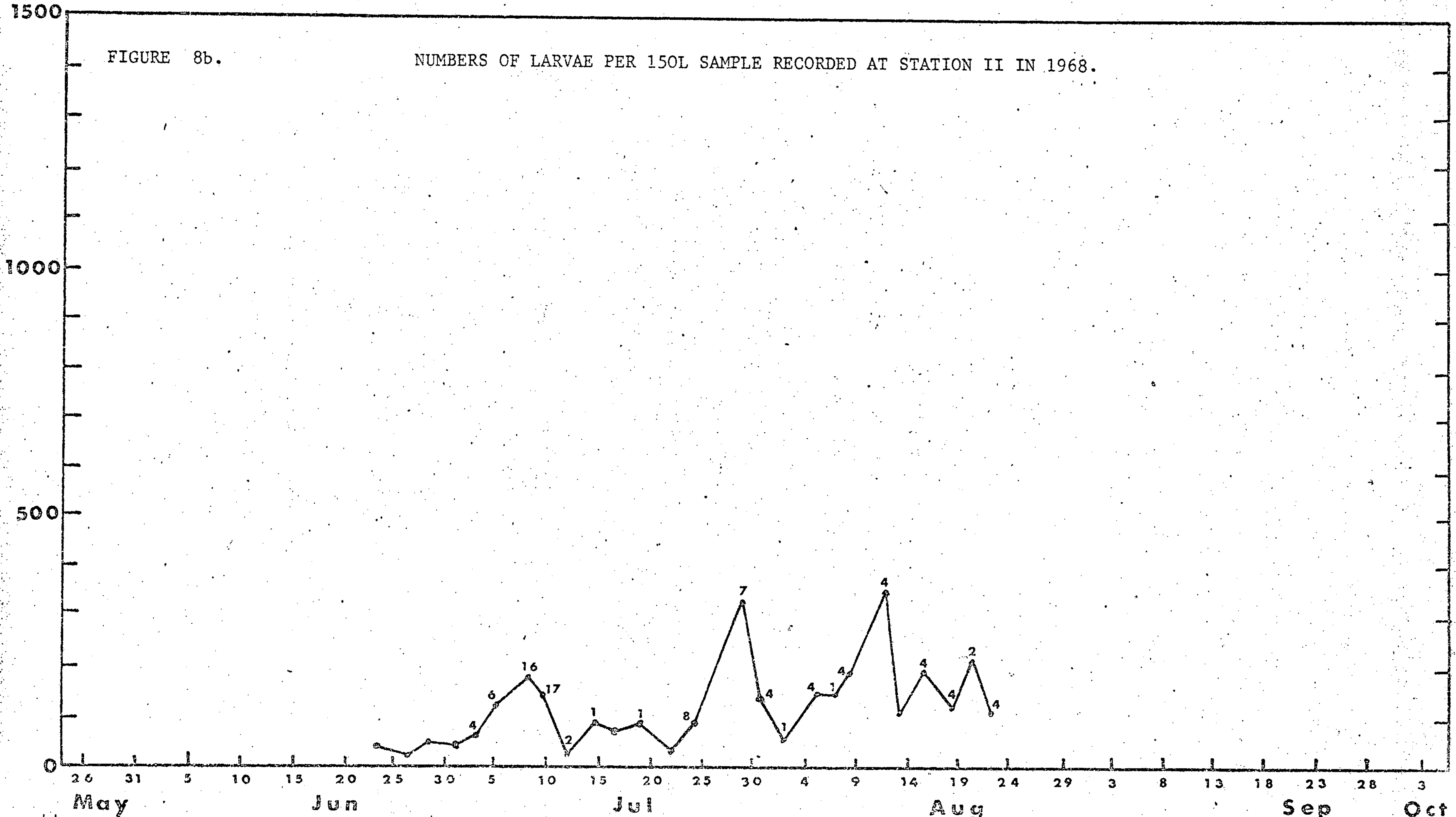


FIGURE 8b.
NUMBERS OF LARVAE PER 150L SAMPLE RECORDED AT STATION II IN 1968.
1500
1000
500
0
26 31 5 10 15 20 25 30 5 10 15 20 25 30 4 9 14 19 24 29 3 8 13 18 23 28 3
May
Jun
Jul
Aug
Sep
Oct
4 6 16 17 2 1 1 8 7 4 1 4 1 4 4 4 4 2 4

FIGURE 8c. NUMBERS OF LARVAE PER 150L SAMPLE RECORDED AT STATION III IN 1968

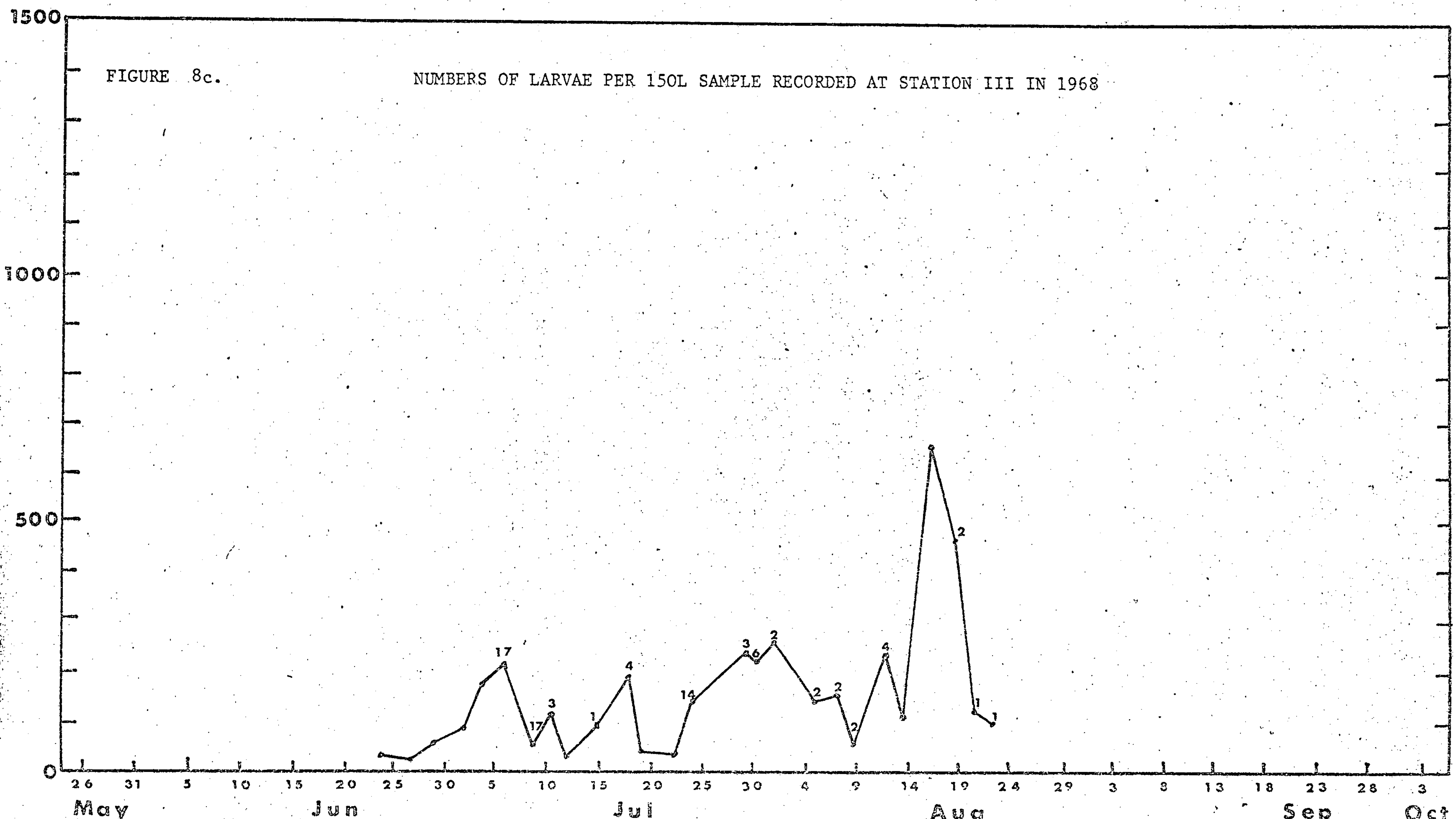
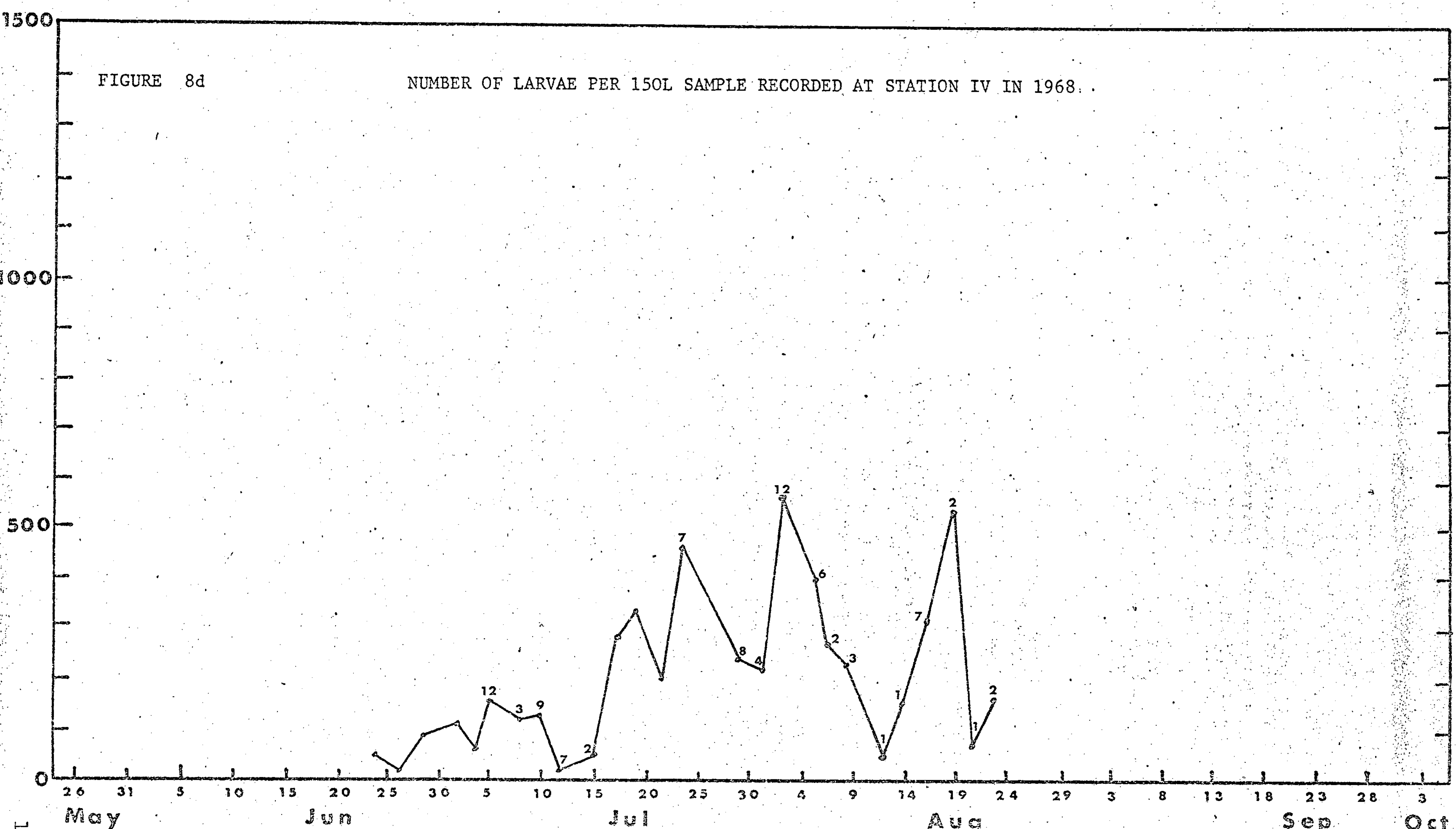


FIGURE 8d

NUMBER OF LARVAE PER 150L SAMPLE RECORDED AT STATION IV IN 1968.



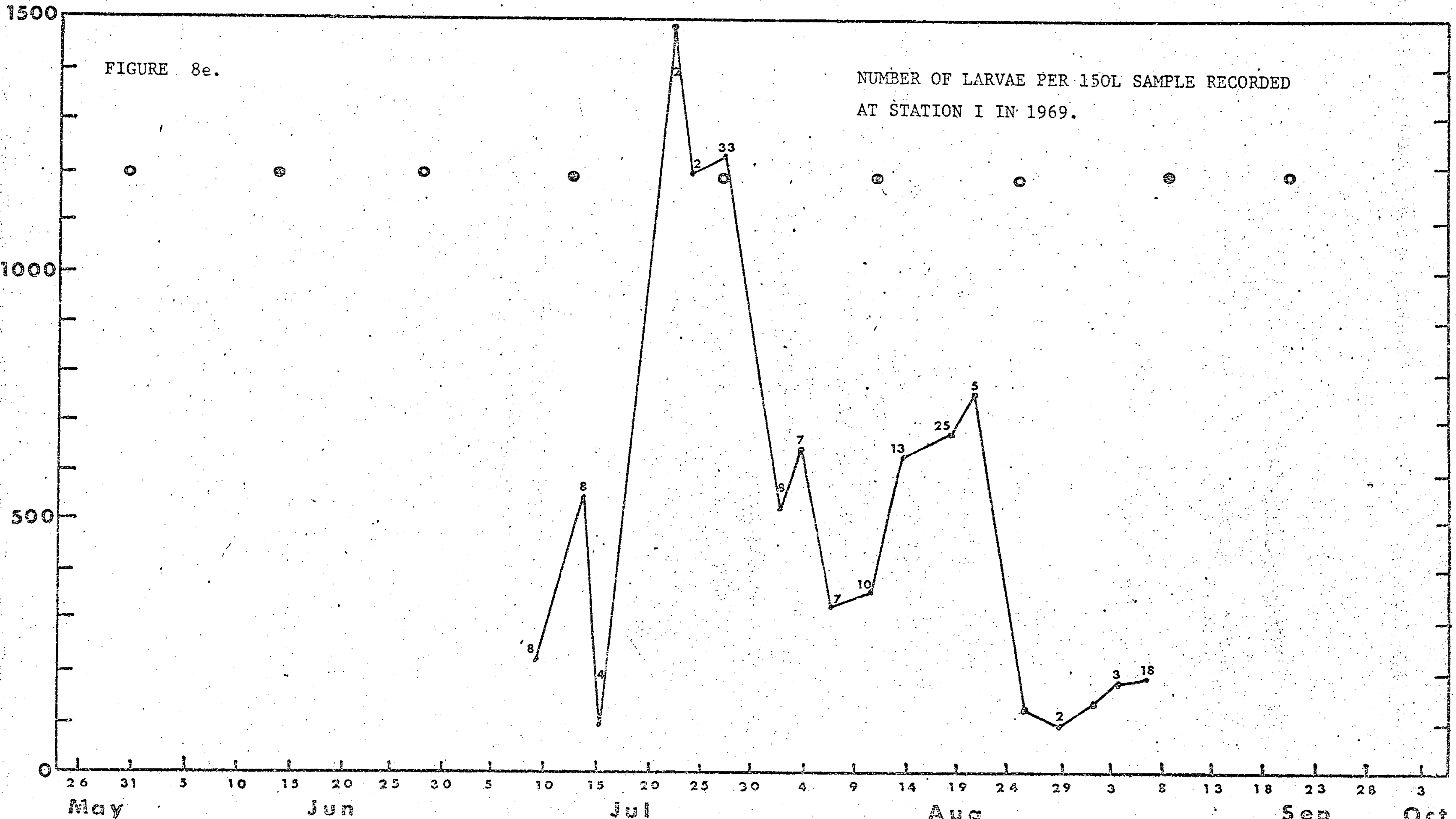


FIGURE 8e.

NUMBER OF LARVAE PER 150L SAMPLE RECORDED AT STATION I IN 1969.

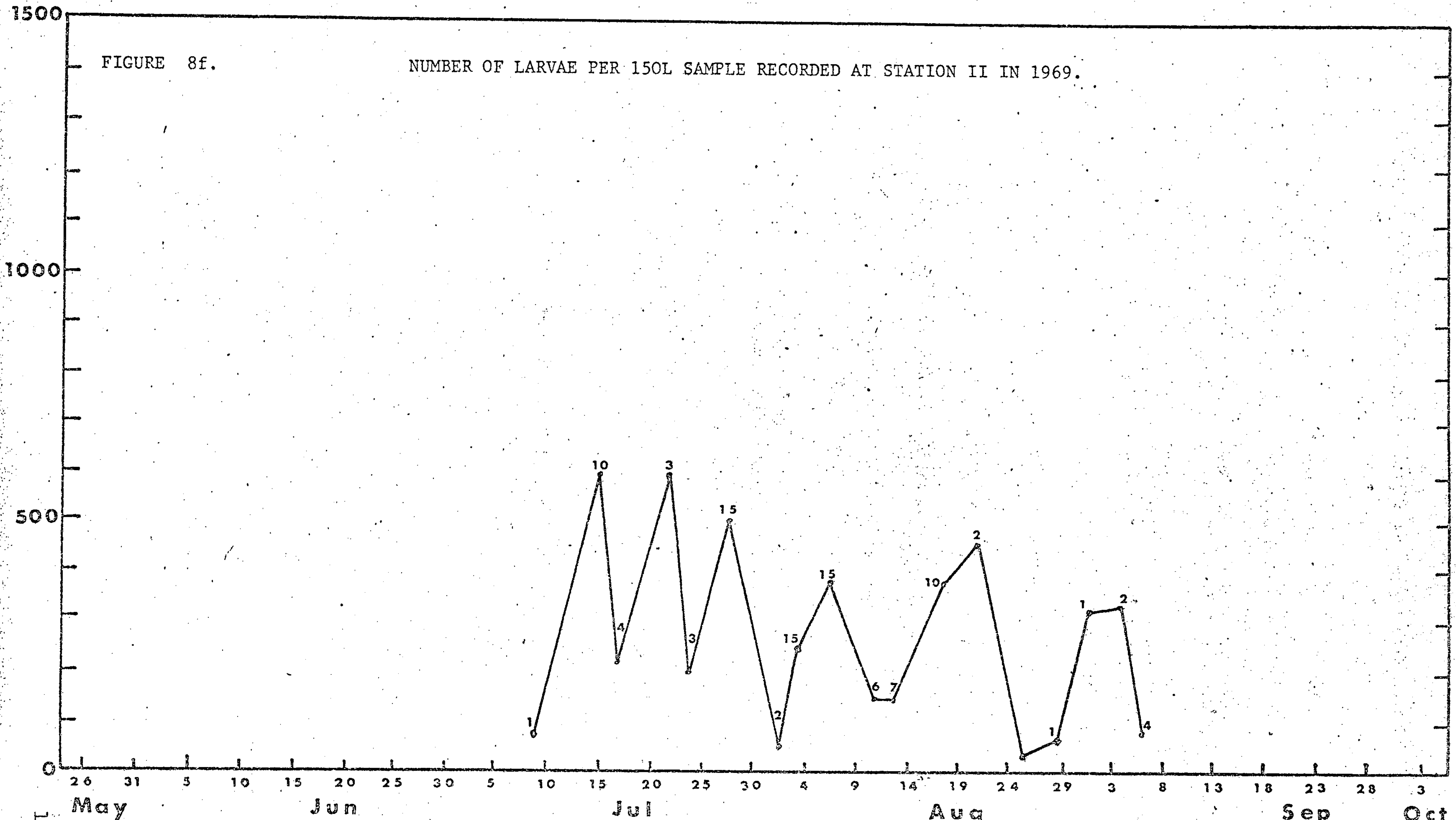


FIGURE 8f. NUMBER OF LARVAE PER 150L SAMPLE RECORDED AT STATION II IN 1969.

FIGURE 8g. NUMBER OF LARVAE PER 150L SAMPLE RECORDED AT STATION III IN 1969.

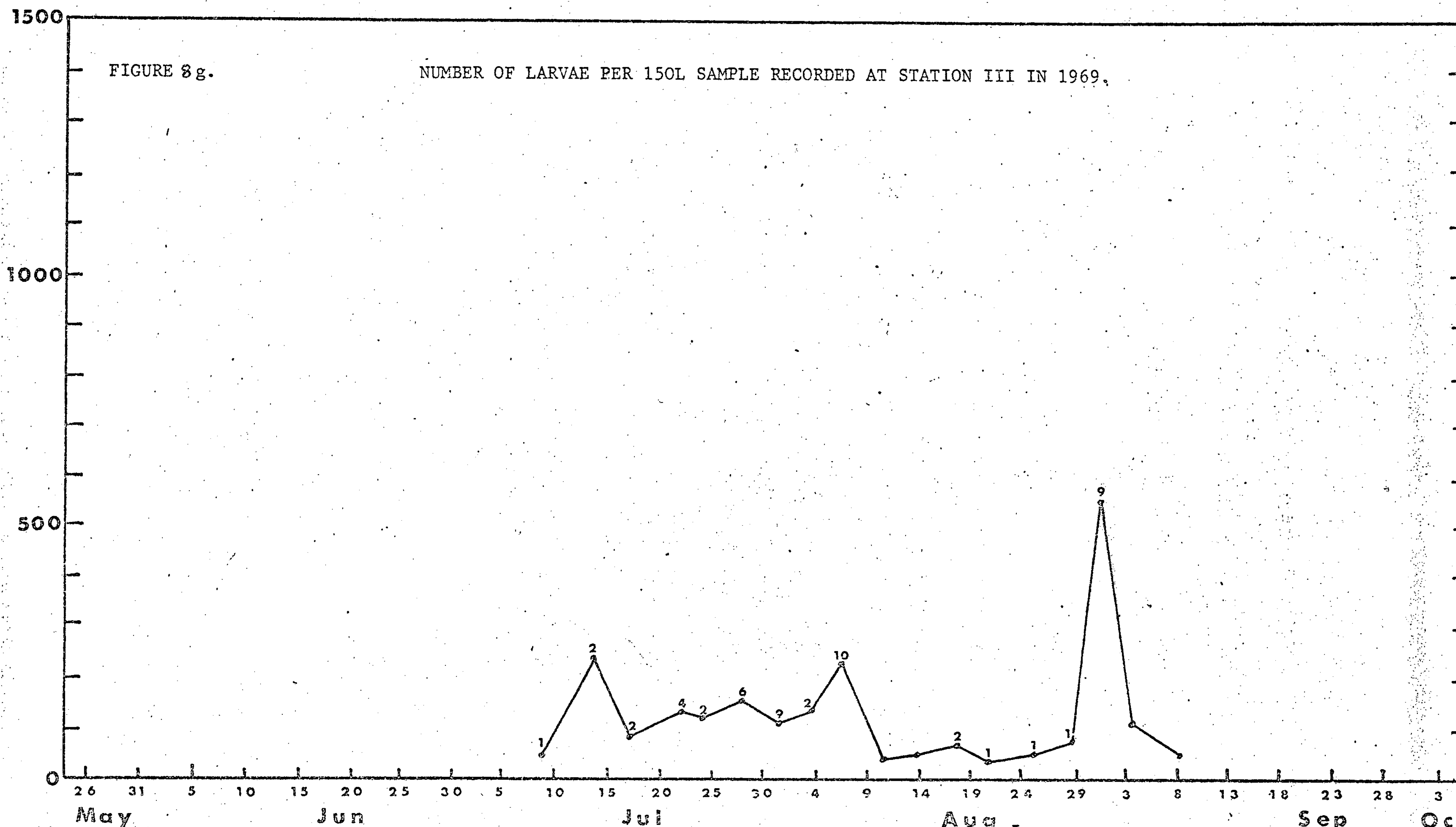


FIGURE 8h. NUMBER OF LARVAE PER 150L SAMPLE RECORDED AT STATION I IN 1970.

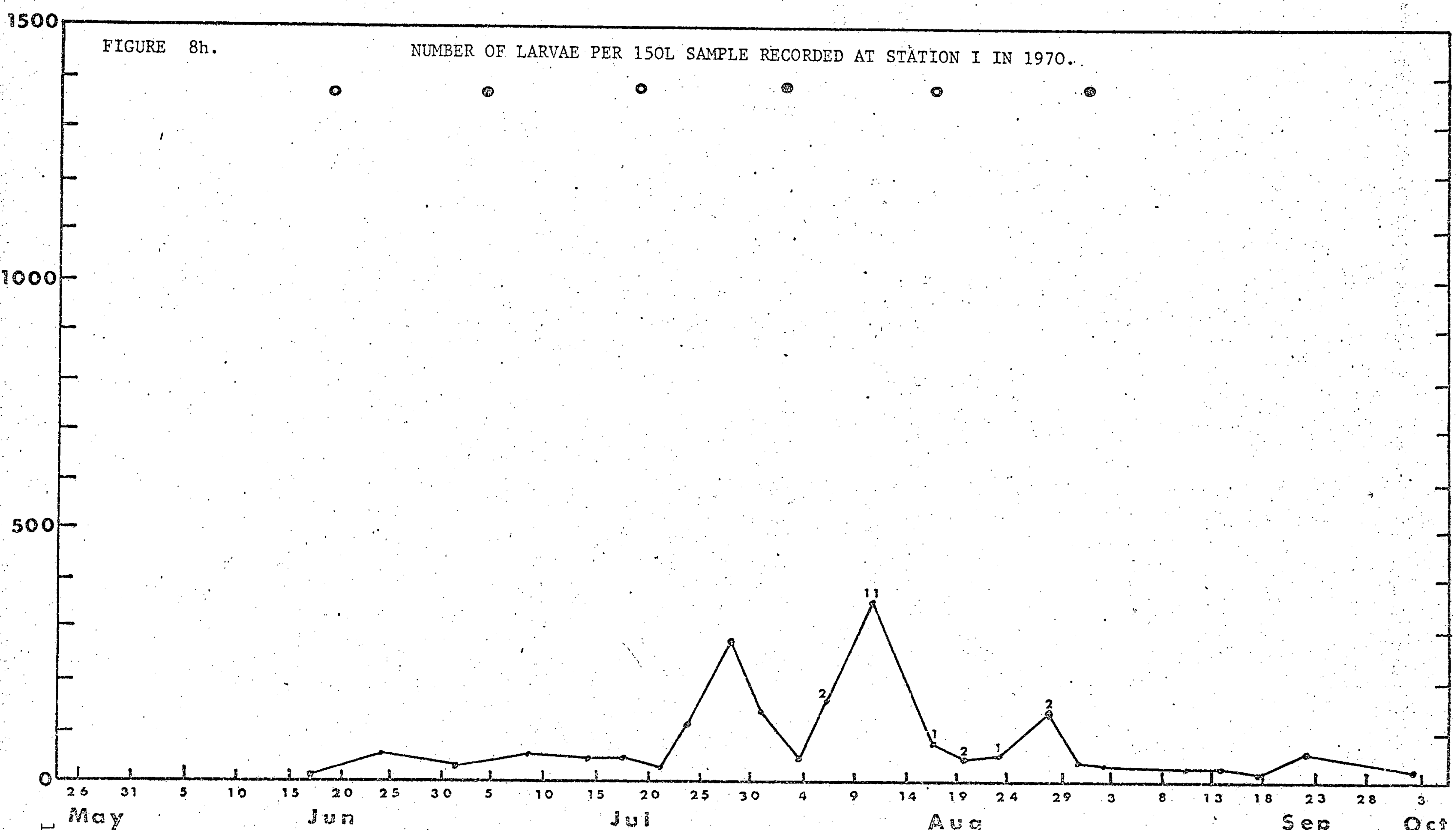
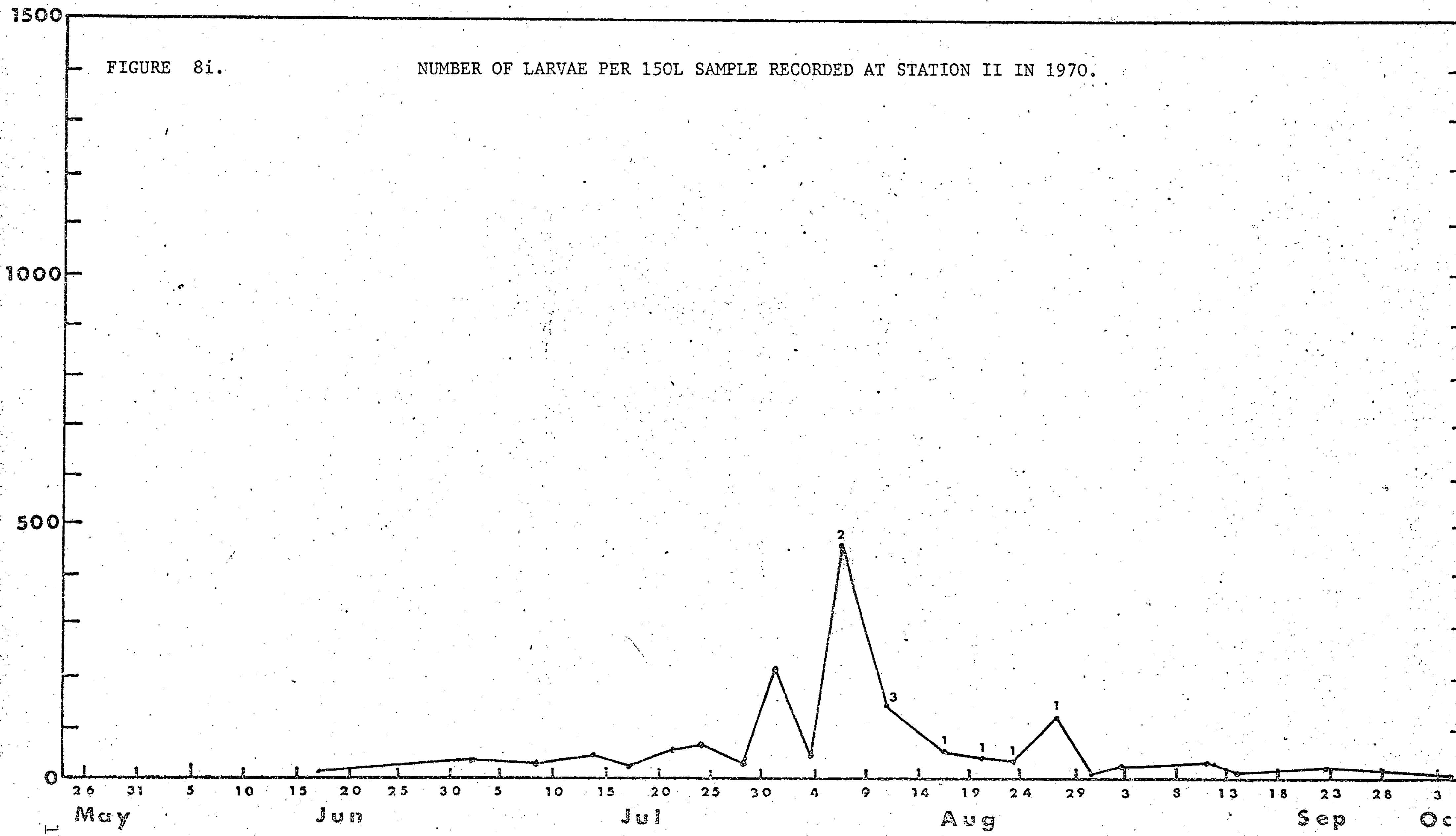


FIGURE 8i. NUMBER OF LARVAE PER 150L SAMPLE RECORDED AT STATION II IN 1970.



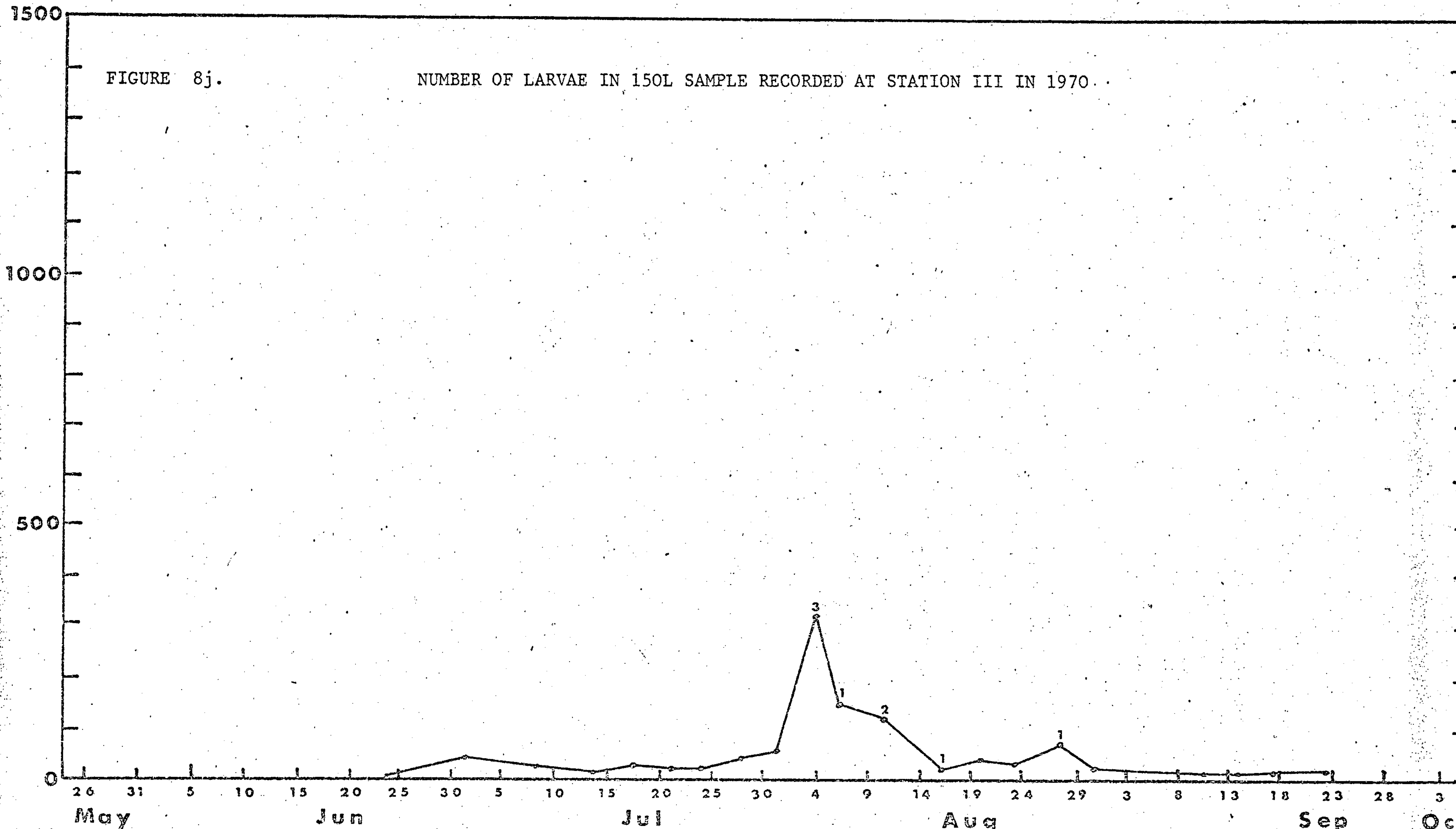


FIGURE 8j. NUMBER OF LARVAE IN 150L SAMPLE RECORDED AT STATION III IN 1970.

FIGURE 8k. NUMBER OF LARVAE PER 150L SAMPLE RECORDED AT STATION IV IN 1970.

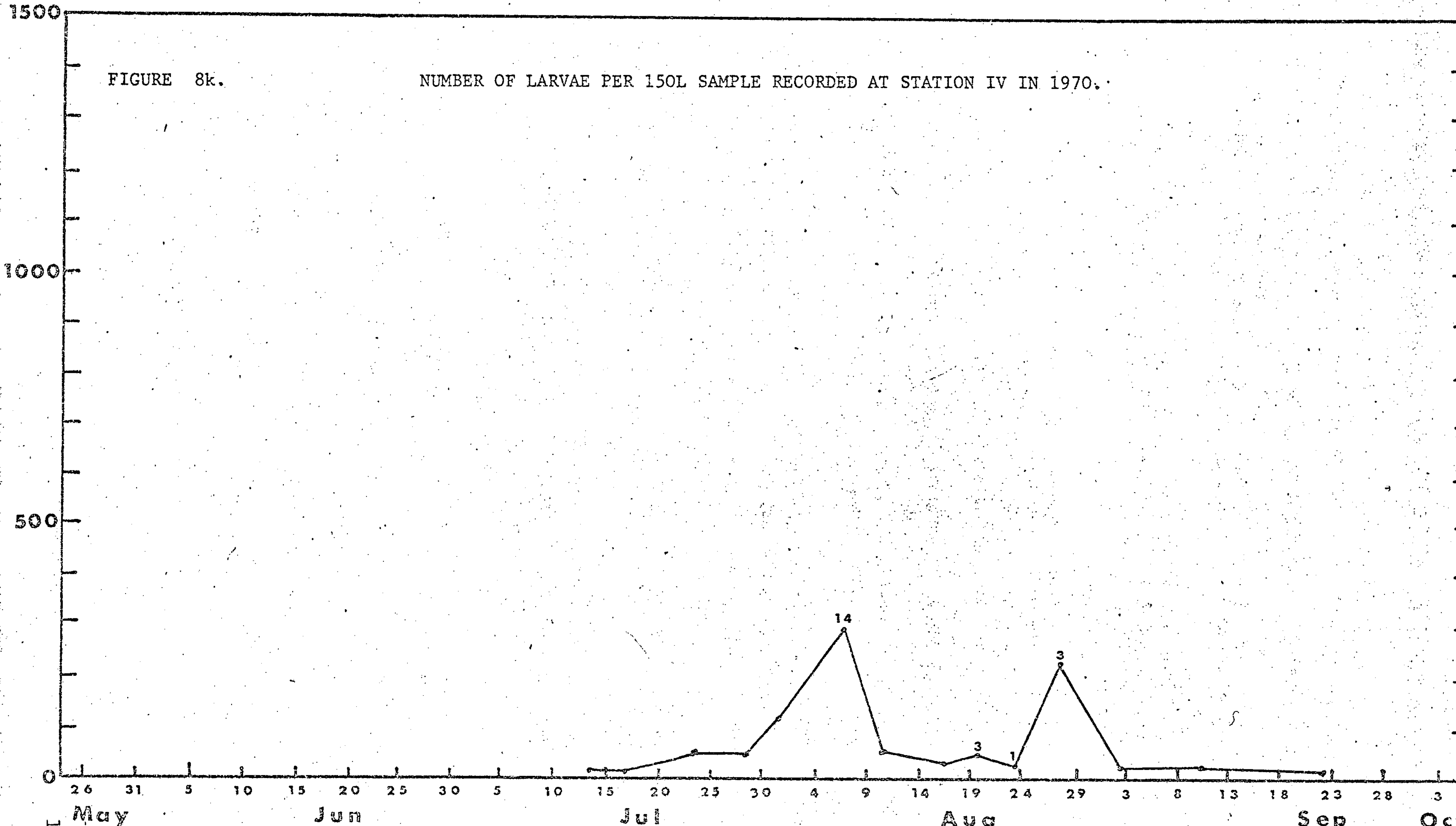
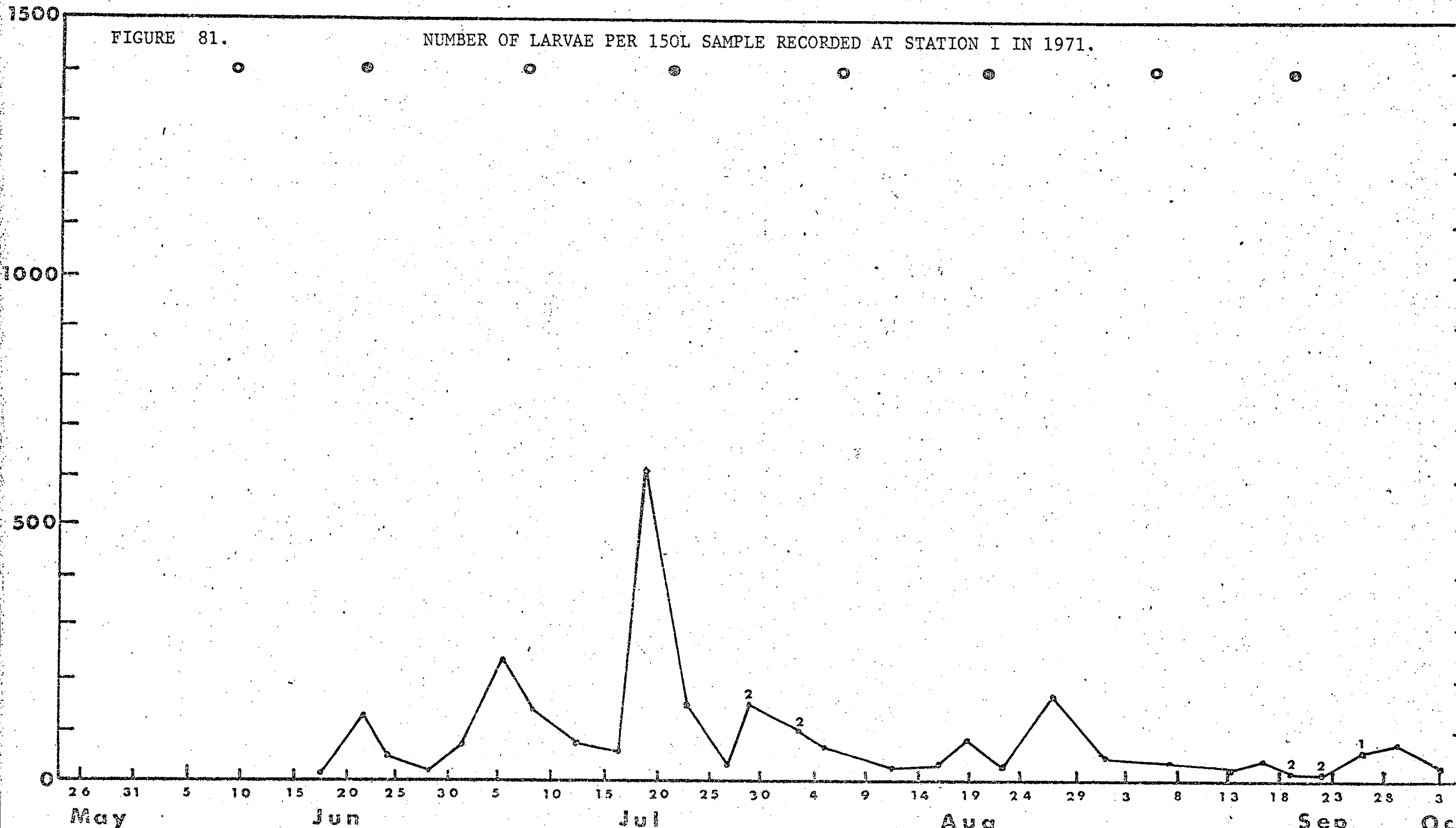


FIGURE 81. NUMBER OF LARVAE PER 150L SAMPLE RECORDED AT STATION I IN 1971.



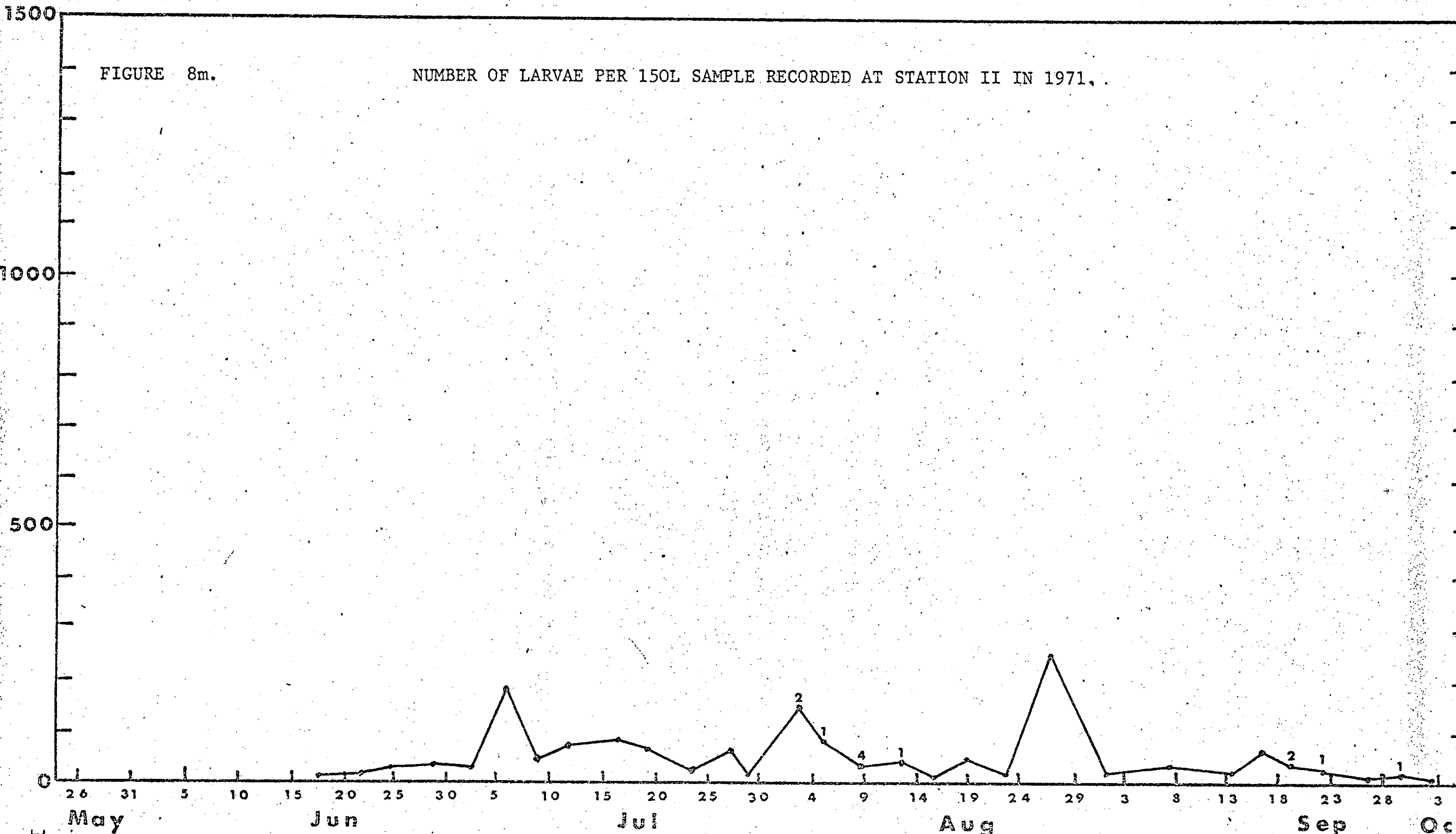
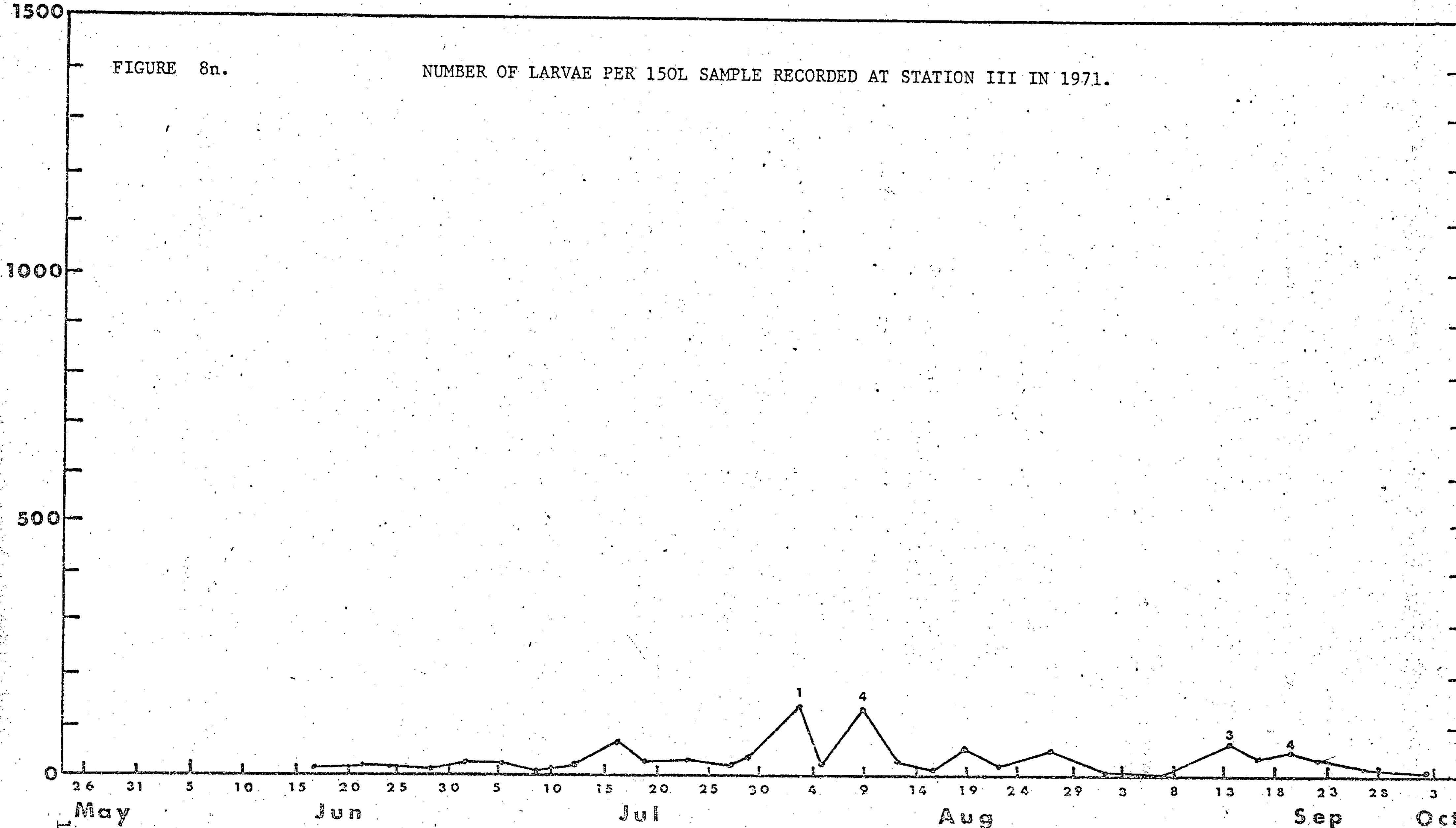


FIGURE 8m.
NUMBER OF LARVAE PER 150L SAMPLE RECORDED AT STATION II IN 1971.
1500
1000
500
0
26
31
5
10
15
20
25
30
5
10
15
20
25
30
4
9
14
19
24
29
3
8
13
18
23
28
3
May
Jun
Jul
Aug
Sep
Oct
2
1
4
1
2
1
1

FIGURE 8n. NUMBER OF LARVAE PER 150L SAMPLE RECORDED AT STATION III IN 1971.



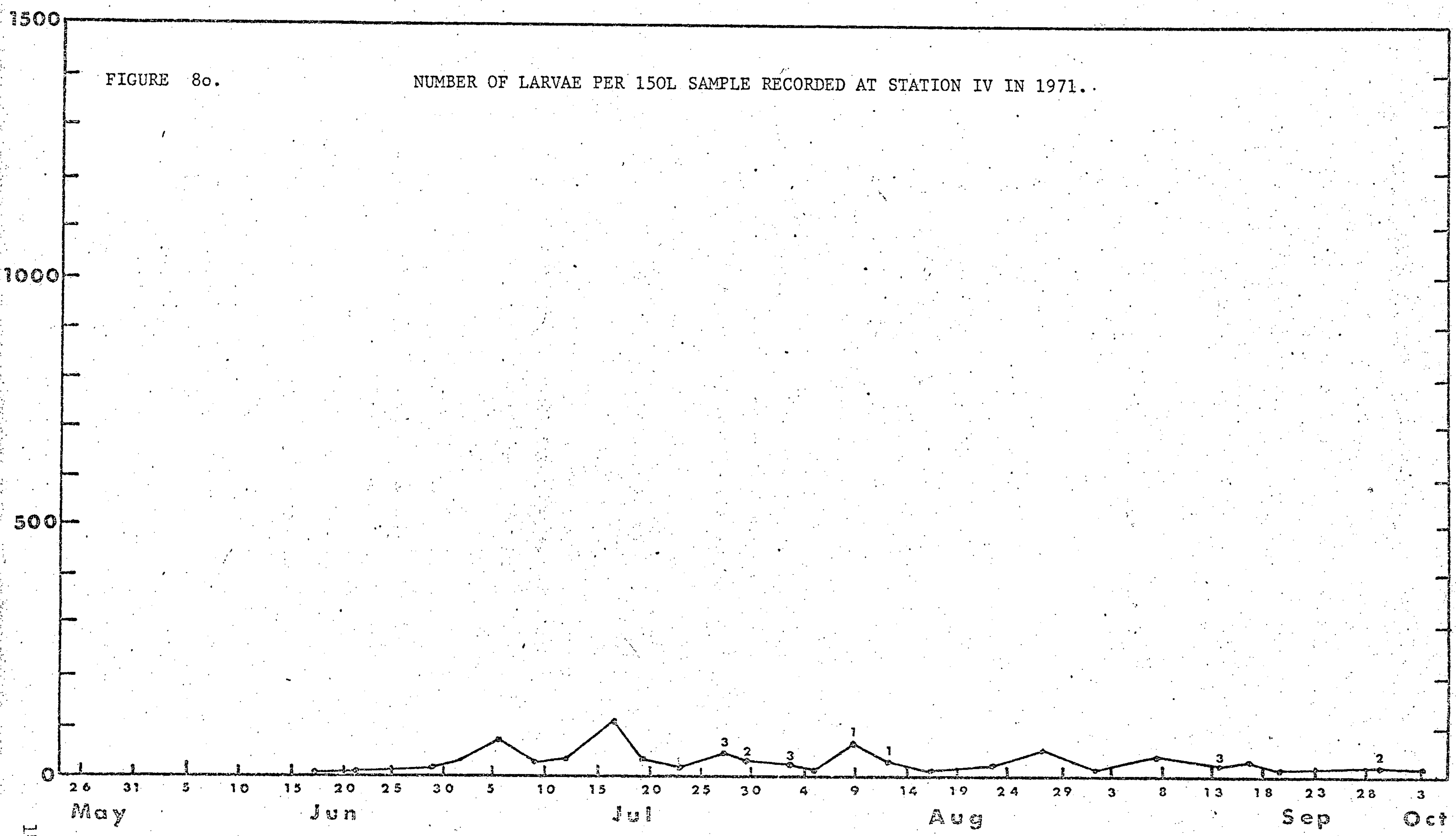


FIGURE 8o. NUMBER OF LARVAE PER 150L SAMPLE RECORDED AT STATION IV IN 1971.

results for each sampling station to produce the averages given in Table 26 because the likelihood of counting the same broods of larvae more than once was remote owing to the rapid dispersal and low survival rate.) The number of eyed larvae was also highest in 1969 with the result that there was a heavy spatfall (see later). The ratio of immature larvae to eyed larvae was similar in 1969 and 1970, but, as would have been expected, a large spatfall did not occur in the latter year because the actual number of larvae reaching the eyed stage was relatively small. This point serves to emphasise that the total number of eyed larvae produced in any year is a more important parameter in the prediction of spatfall than the proportion of eyed larvae in the total production of larvae.

Larvae production was very poor in 1970 and 1971 and the possible reasons for this decline are discussed in a later section.

Dispersal of Larvae

At Clarinbridge larvae are dispersed westwards on ebbing tides as indicated in Tables 19 and 20 Float tests carried out in 1968 showed that on an ebbing neap tide, larvae could be carried as far as the western end of Eddy Island -- a distance of approximately 3 miles from the centre of the oyster bed -- and that on successive tides the larvae could be lost completely from the Clarinbridge estuary. Current measurements, made at approximately 0.7 metre above the seabed in July 1971, indicated speeds of 0.30 to 0.70 knots at Station 1 and 0.60 to 0.75 knots at Station III between slack-water and a fully ebbing spring tide. These flow measurements indicate that larvae could be carried approximately $4\frac{1}{2}$ miles away from the oyster bed on one spring tide. Surface currents were not measured, but if, as is usually the case, the flow of surface water is faster than the flows indicated above, it is possible that a substantial proportion of the larvae population could be swept further than $4\frac{1}{2}$ miles on an ebbing spring tide.

Current measurements on flooding tides at Station I ranged from 0.30 to 0.45 knots, indicating that fewer larvae would be returned to the vicinity of the oyster bed than were initially dispersed, unless factors other than currents were affecting the movements of larvae.

Wood and Hargis (1971) discovered that larvae of *Crassostrea virginica* tended to stay in their area of origin despite tidal influences. They found that although horizontal water speeds exceeded larvae swimming speeds, vertical water movements were slower than larvae which could negotiate a 10m column of water in about 15 minutes. From this information it was concluded that if larvae are to be retained in an estuary they must spend at least as much time in the lower landward moving strata as in the upper seaward moving strata. The major difficulty in proving this mode of retention is, according to these authors, that a sensory system to detect the direction of water movement when the oyster is itself a part of the moving mass has not been discovered.

Vertical selection could be possible, and according to some authors quoted by Wood and Hargis, larvae swim with the flood tide and rest on or near the bottom during the ebb tide. Such behaviour, it was suggested, may be a reaction to changes in salinity which accompany tidal exchange. On *C. virginica* oyster beds, surface water salinity may rise considerably on a flooding tide, but as Table 27 shows only small salinity changes occur during tidal exchange, suggesting that this mode of larvae retention does not operate at Clarinbridge.

Plankton samples were taken at only one depth throughout Clarinbridge investigations and so it is impossible to provide evidence of vertical movements of larvae or information on the vertical distribution of various size groups of larvae. The limited information available does not provide sufficient insight into the movements and dispersal of larvae at Clarinbridge to allow a mode of larvae retention to be discerned. Wood and Hargis, after their intensive study on the dispersal of *C. virginica* larvae, had to conclude that with the large numbers of larvae involved, passive transport was possibly sufficient to maintain estuarine oyster population. It is suspected, therefore, that a similar situation prevails at Clarinbridge.

Environmental Factors Affecting Larvae Production

The production of larvae, their rate of development and intensity of subsequent settlement all vary from year to year. Several explanations have been advanced to account for such fluctuations. These include variations in physical conditions of tide and weather and the size and composition

TABLE 27.

SALINITY CHANGES OVER A TIDAL CYCLE AT CLARINBRIDGE IN JULY, 1971.

Station	I		I		III		IV	
Date	July 8th		July 31st		July 9th		July 10th	
Sample	Low Water		High Water		Low Water		Low Water	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
1	29.0	29.6	31.1	31.9	30.8	32.1	29.5	30.3
2	30.3	30.4	31.5	32.0	31.6	32.4	31.2	31.5
3	30.4	30.6	30.4	31.8	31.8	32.1	31.4	31.4
4	30.4	30.6	30.6	31.6	31.7	32.1	31.2	31.4
5	30.4	30.6	31.3	31.5	32.0	32.1	31.2	31.4
6	30.6	30.8	31.5	31.5	31.9	32.0	31.5	31.7
7	30.7	30.8	31.3	31.4	31.9	32.0	31.5	31.5
8	30.7	30.9	31.2	31.2	31.6	31.6	31.6	31.8
9	31.0	31.1	31.0	31.0	31.7	32.0	31.5	31.5
10	31.0	31.1	31.0	31.0	31.6	32.0	31.6	32.0
11	30.9	31.1					31.6	31.8
12							31.6	31.8
	High Water		Low Water		High Water		High Water	

of the breeding stock (Waugh, 1957a); food shortage, competition and predation (Knight-Jones, 1952). Often these factors work in combination so that the immediate cause of fluctuations are not always readily apparent. This seems to be the case at Clarinbridge where considerable variations in larvae production were observed over the past four breeding seasons.

(a) Physical conditions

Reference to Figures 8 and 9, which present larvae production and water temperature over the oyster bed, indicates that the first peak larvae releases occurred several days after a steep rise in water temperature. In 1968, the peak on August 1st occurred 9 days after a temperature increase from 15.0°C to 18.0°C in 7 days. In 1969, the major release on July 22nd followed a rise from 15.8°C to 19.4°C between July 9th and July 14th. The first peak of 1970 (July 28th) followed a rise from 14.0°C to 17.2°C in the 6 days prior to July 8th and a drop in temperature between July 8th and July 15th, followed by a slow increase from 15.2°C to 16.5°C on July 24th. In 1971, a rise of 14.9°C to 18.1°C between June 28th and July 8th preceeded the peak larvae release on July 19th. These figures suggest that the first mass spawnings were induced by sharp increases in temperature and that larger mass spawnings occurred when the temperatures exceeded 19°C. They also indicate that incubation periods, prior to peak releases, were approximately 9 days in 1968 at a temperature between 17°C and 18°C, approximately 8 days in 1969 at between

$17.0^{\circ}C$ and $19.4^{\circ}C$ and approximately 11 days in 1971 at $17.0^{\circ}C$ to $18.1^{\circ}C$. The incubation period in 1970 is masked, apparently, by the effects of a drop in temperature after the initial steep rise.

Subsequent peaks of larvae release were not associated with further steep increases in temperature, possibly because spawning continued at a more even rate while the higher temperatures prevailed.

These observations help to explain why peak larvae releases occurred when they did in a given year, and why a larger mass spawning was recorded in 1969 than in the other three years. However, they do not explain why there were probably more oysters ready for spawning early in the season in 1969 than in 1968, 1970 or 1971, or why the rate of development of pelagic larvae was so poor in 1971.

In an attempt to explain these variations in larvae production and development, salinity, rainfall and sunshine records have been considered, in addition to water temperature records already presented.

Salinity (Figures 9a to 9d) was highest during the 1968 summer period, remaining above 32‰ throughout July and the first half of August. In 1969, when summer rainfall was fairly low, salinity remained below 30‰ during July, rising to approximately 32‰ for a short period in early August, after which it returned to its former level. In 1970 salinity exceeded 30‰ from early July to the end of September despite the relatively high rainfall and in 1971 it exceeded 31 for approximately the same period.

Water temperature, rainfall and sunshine records have

FIGURE 9a. SURFACE WATER SALINITY AND TEMPERATURE RECORDED AT STATION I IN 1968

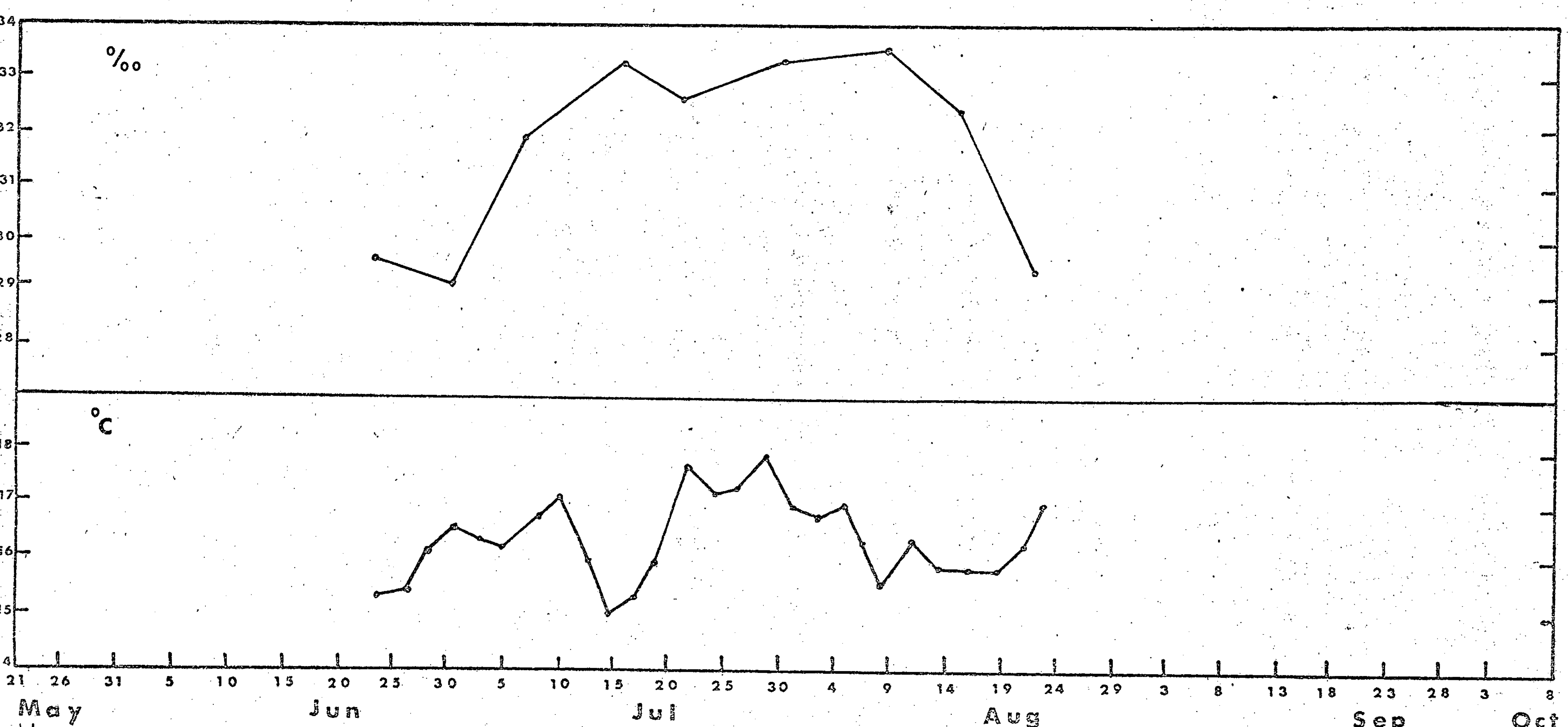


FIGURE 9b. SURFACE WATER SALINITY AND TEMPERATURE RECORDED AT STATION I IN 1969.

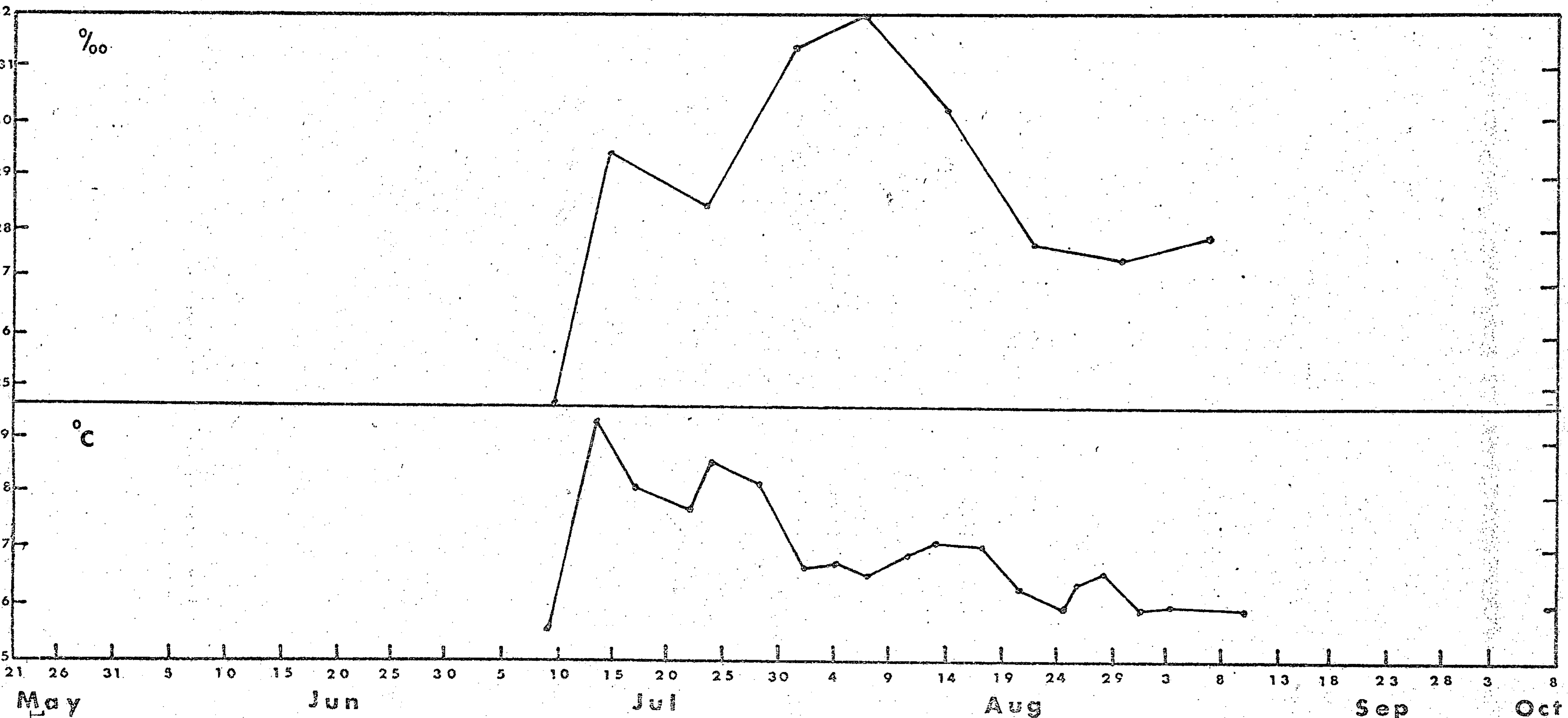


FIGURE 9c. SURFACE WATER SALINITY AND TEMPERATURE RECORDED AT STATION I IN 1970.

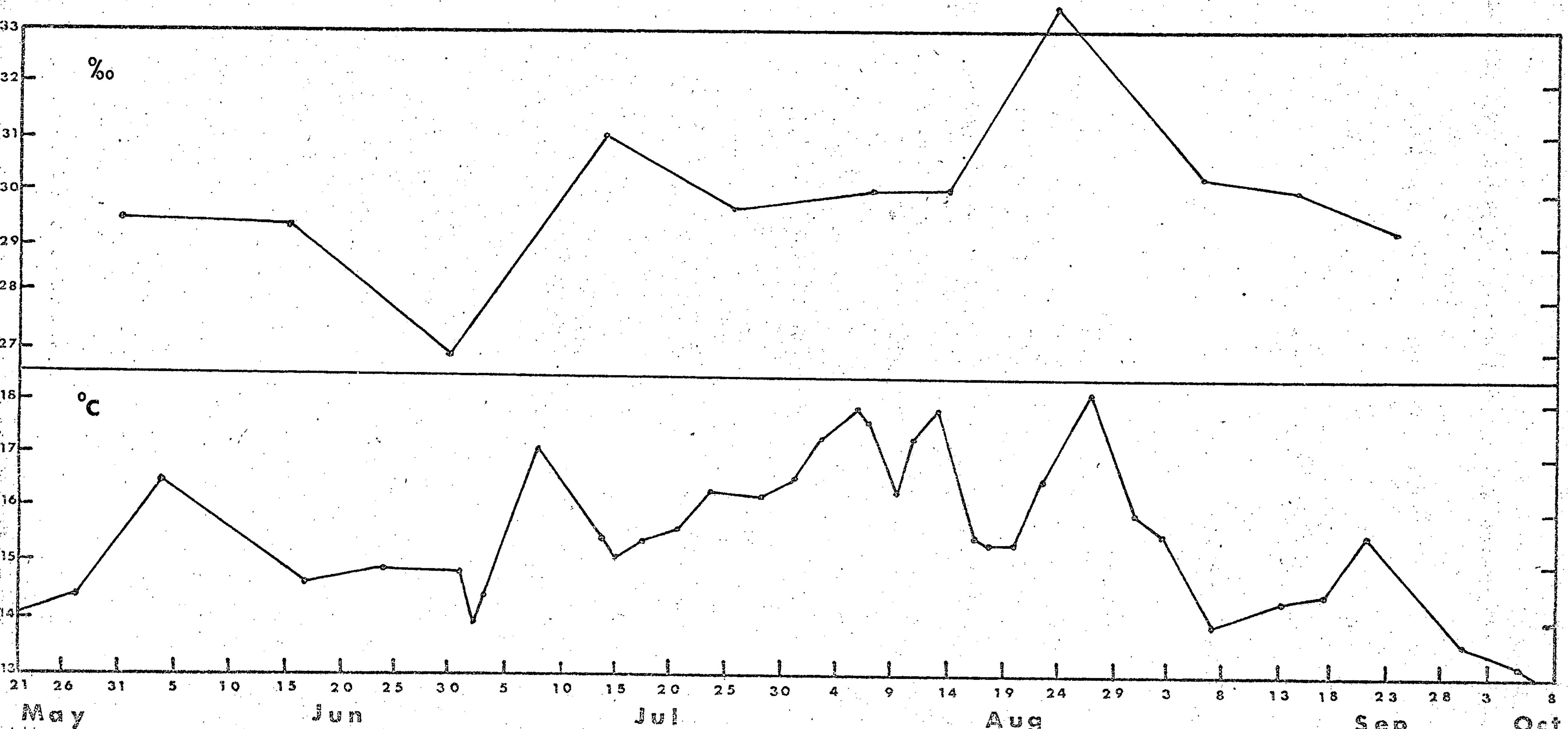
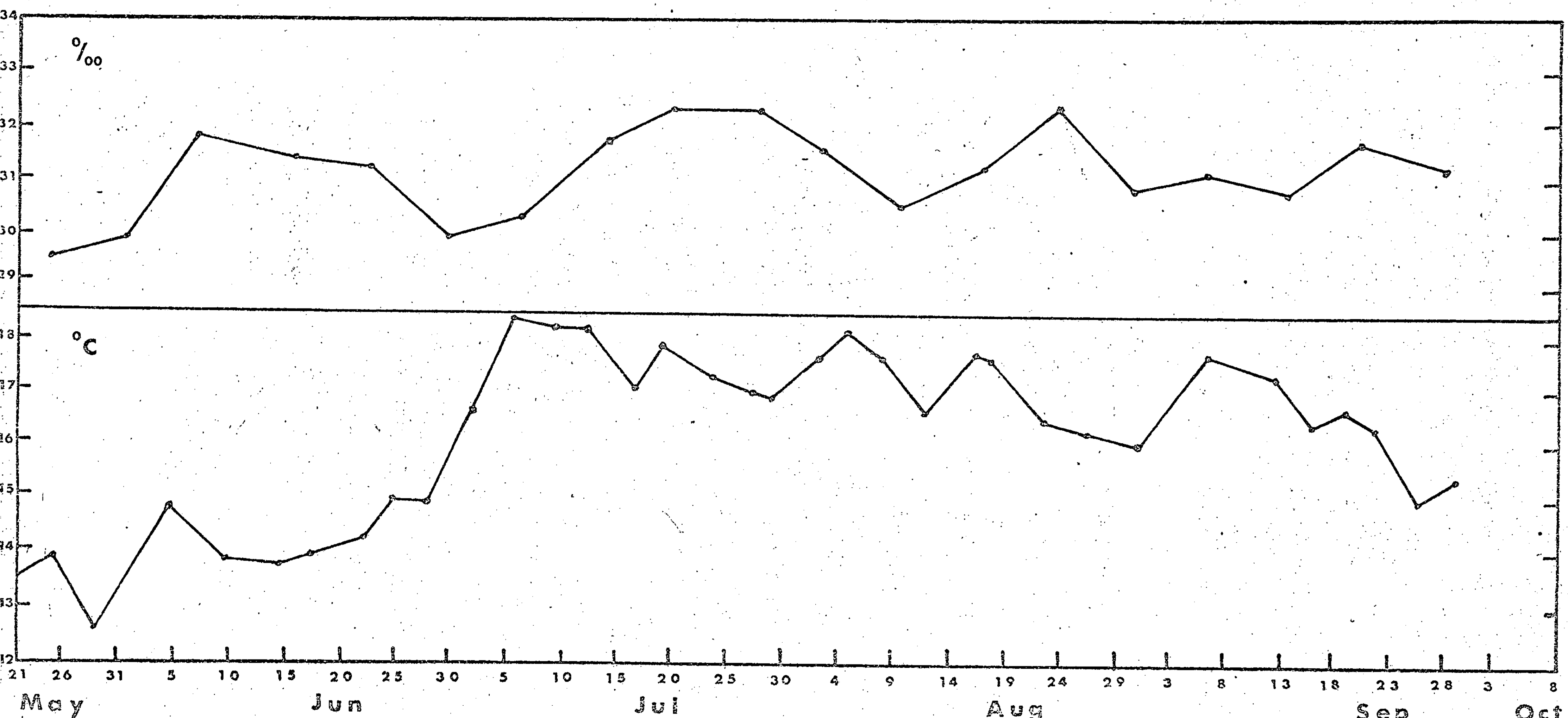


FIGURE 9d. SURFACE WATER SALINITY AND TEMPERATURE RECORDED AT STATION I IN 1971.



been analysed for the periods leading up to the breeding seasons of 1969 to 1971. Tables 28a,b,and c present the cumulative totals of water temperature (in day degrees),sunshine (hours) and rainfall (mm) prior to various stages in the breeding cycle from: (1) January 1st; (2) from the date when the water temperature reached 10°C (the lower growth threshold); (3) from the date when the temperature reached 15°C (approximately the lower threshold for mass spawning). In addition, the cumulative amounts of temperature, rainfall and sunshine recorded for the periods when the water temperature exceeded 10°C, 15°C and when larvae were recorded in the water are also presented.

The temperature data show that, in terms of day-degrees, 1971 was the warmest of the study years. However, it will be noted that more day-degrees were recorded between the attainment of 15°C and the first major larvae release in 1969 which occurred on July 22nd -- 2 days before first spat settlement was recorded. These observations are in accordance with those mentioned earlier -- i.e., generally higher temperatures were recorded in July 1969 than in the same period in the other three years. The cumulative temperature records show that more heat was received between January 1st and the first spat settlement in 1971 than 1969, but the converse was the case between the onset of growth (and possibly gonad development) at 10°C and the end of July (the approximate time of first settlement).

In 1970 more heat was recorded between the 10°C threshold and the onset of larvae release and spat settlement than in any other year but less was recorded after the attainment of 15°C than in 1969. Least heat was recorded between the 10°C threshold and the onset of larvae release and spat settlement in 1968 -- when large numbers of larvae were recorded.

The rainfall data show that 1971 was the driest year during the investigation, although more rain fell during the 1971 breeding season than during the corresponding period in 1969. However, during the period between the attainment of the growth threshold and the onset of larvae release least rainfall was received in 1971 and the amount of rainfall recorded between the attainment of the spawning threshold and the first spat settlement was approximately one-third of that recorded in 1969 and 1970. Similarly, the amount of sunshine recorded early in the breeding season was least in 1971, although more was recorded between the attainment of the growth threshold and the onset of larvae release in 1969 and 1970.

It would appear, therefore, that the variations in the timing and intensity of larvae production observed at Clarinbridge are influenced by the interaction of water temperature, salinity (which does not appear to be immediately influenced by rainfall during the summer) and the sunshine. It may be speculated, however, that while these factors can directly affect the oyster breeding cycle, they also exerted an indirect effect by limiting the food supply, both prior to the breeding season and during it. In the years of high salinity (1968, 1970 and 1971) there may have been a deficiency of nutrients in the estuary as a result of low freshwater discharges, which may have led to a low level of suitable

TABLE 28a.

CUMULATIVE WATER TEMPERATURE DATA (°C)

(1) From 1st January

To	1968	1969	1970	1971
1st larvae	1440.6	1469.3	1599.5	1618.0
1st spat	2082.5	2024.4	2367.4	2204.6
30th Sept.	3059.7	3158.4	3266.5	3384.1
1st larvae to 30th Sept.	1619.1	1689.1	1667.0	1766.1
Whole year	3910.9	4073.5	4237.4	4399.8

(2) From 10°C

To	1968	1969	1970	1971
1st larvae	111.0	149.5	209.5	123.5
1st spat	259.5	442.0	495.5	330.5
30th Sept.	676.0	815.0	825.0	843.0
1st larvae to 30th Sept.	565.0	665.5	615.5	719.5
10°C - 10°C	1003.2	1374.5	1417.5	1487.0

(3) From 15°C

To	1968	1969	1970	1971
1st larvae	1.0	9.5	19.5	0
1st spat	14.5	107.0	85.5	67.0
30th Sept.	57.0	143.5	120.5	178.5
1st larvae to 30th Sept.	56.0	134.0	101.0	178.5
15°C - 15°C	57.0	143.5	120.5	178.5

TABLE 28b.

CUMULATIVE SUNSHINE DATA (hrs)

(1) From 1st January

To	1968	1969	1970	1971
1st larvae	758.0	722.4	693.6	667.1
1st spat	898.0	913.1	928.7	879.7
30th Sept.	--	1212.4	1145.1	1189.8
1st larvae to 30th Sept.	--	490.0	451.5	522.7
Whole year	--	1389.5	1319.7	1392.2

(2) From $10^{\circ}C$

To	1968	1969	1970	1971
1st larvae	194.0	303.0	340.8	414.0
1st spat	444.0	493.7	555.9	626.6
30th Sept.	--	793.0	772.3	936.7
1st larvae to 30th Sept.	--	490.0	451.5	522.7
$10^{\circ}C$ - $10^{\circ}C$	--	881.4	882.2	1070.4

(3) From $15^{\circ}C$

To	1968	1969	1970	1971
1st larvae	--	112.6	132.2	0
1st spat	--	303.3	367.3	188.6
30th Sept.	--	580.5	533.7	498.7
1st larvae to 30th Sept.	--	467.9	451.5	498.7
$15^{\circ}C$ - $15^{\circ}C$	--	580.5	583.7	498.7

TABLE 28c.

CUMULATIVE RAINFALL DATA (mm)

(1) From 1st January

To	1968	1969	1970	1971
1st larvae	416.0	399.2	423.8	331.7
1st spat	478.0	501.5	566.3	402.2
30th Sept.	--	611.5	781.6	575.5
1st larvae to 30th Sept.	--	212.3	357.8	243.8
Whole year		993.8	1101.6	815.7

(2) From $10^{\circ}C$

To	1968	1969	1970	1971
1st larvae	99.0	108.5	129.2	91.8
1st spat	134.0	210.8	271.7	162.3
30th Sept.	--	320.8	487.0	335.6
1st larvae to 30th Sept.	--	212.3	357.8	243.8
$10^{\circ}C$ - $10^{\circ}C$		525.1	711.1	502.4

(3) From $15^{\circ}C$

To	1968	1969	1970	1971
1st larvae	--	10.7	5.5	0
1st spat	--	113.0	148.0	41.4
30th Sept.	--	223.0	363.3	214.7
1st larvae to 30th Sept.	--	212.3	357.8	243.7
$15^{\circ}C$ - $15^{\circ}C$	--	223.0	363.3	214.7

phytoplankton production.

It would have been expected that the sharp rise in water temperature in late June 1971, would have been followed by a large release of larvae, as was the case in 1969, had the oyster population been in suitable breeding condition. Apparently environmental conditions in 1971 were inadequate for large-scale gonad maturation early in the season. Furthermore, the poor development and survival of larvae in 1971 point to the fact that inadequate conditions prevailed throughout the breeding season. A similar situation prevailed in 1970, although conditions were probably slightly more favourable in that year.

(b) Biological factors

The oyster population and larvae production

The size of the breeding stock greatly influences the number of larvae produced during any particular breeding season (Korringa, 1941; Knight-Jones, 1952). The number of larvae released also depend on the size-frequency distribution of the population, the sex ratio, the number of oysters functioning as females throughout the season and the rate of fertilization which probably depends directly on the dispersion of the parent stock.

Cole (1941) estimated the fecundity of various size groups of oysters but more recently Walne (1964) has provided more accurate figures for larvae production which he, more correctly, designates fertility. Table 29 gives Walne's estimates of the fertility of various size classes of mature oysters.

TABLE 29.

THE FERTILITY OF VARIOUS SIZE GROUPS OF *OSTREA EDULIS*

Mean Diameter (mm)	Approximate Age	Fertility (No. larvae)
40	1	100,000
57	2	540,000
70	3	340,000
79	4	1,000,000
84	5	1,260,000
87	6	1,360,000
90	7	1,500,000

TABLE 30.

POTENTIAL LARVAE PRODUCTION AT CLARINBRIDGE

Date of Survey	Aug. 1969	Nov. 1970	Apr. 1971	Nov. 1971	Jan. 1972
Estimated[1] total population 20mm	7,040,000	9,900,000	8,470,000	6,930,000	8,772,500
Estimated number of larvae	36×10^{11}	26×10^{11}	37×10^{11}	32×10^{11}	38×10^{11}
Estimated[2] number surviving to eyed stage	36×10^{9}	26×10^{9}	37×10^{9}	32×10^{9}	38×10^{9}

1 Estimate standardised for a population covering 110 hectares
2 Assuming 1% survival rate (cf. Korringa, 1941 - 10%)

Using these figures and the population size frequency distribution recorded during grab surveys (see Chapter V) estimates have been made of the potential larvae production at Clarinbridge, assuming that every oyster larger than approximately 35mm. in diameter bred at least once as a female during the season. The results are presented in Table 30.

The population estimates were not of high precision, for reasons explained elsewhere, and although they were made at times remote from the breeding season the figures in Table 30 show the enormous potential production inherent in the Clarinbridge oyster stocks, even when small and depleted of large oysters. It is not known how many eyed larvae survive to settle but the figures presented in Table 29 suggest that there should always be a great potential for high settlement rates.

The figures presented in Table 30 must, however, be qualified because it is almost certain that all the mature oysters in the population could not have produced larvae successfully, particularly in 1970 and 1971 when larvae numbers were very low relative to the estimated adult population size. It can be speculated, from the uneven dispersion of oysters observed during grab surveys (Chapter V) that many oysters may be sufficiently isolated from their neighbours to prevent fertilization. It might be possible also that the wider dispersal of oysters as a result of dredging with power boats, possibly in combination with overfishing, is reducing the chances of effective fertilization.

The intensity of larvae production may also be affected by oyster condition (Marteil, 1960). Walne (1964) showed that fertility can rise with an increase in the condition factor (see Chapter V) and stated that the fertility can double with an increase in the dry weight condition index from 90 to 150. Therefore, he suggested, it must be assumed that the average condition of a population will affect its average fertility. No condition tests were performed at Clarinbridge in 1968 and 1969 when larvae production was high. However, dry weight condition indices are presented for the relevant periods in 1970 and 1971 in Table 31. These figures show that there was little difference between the condition indices in the two years and that the indices did not reach an optimum of 150 in either year. Since a condition index of 150 is rarely attained at Clarinbridge -- the figures shown in Table 31 being fairly typical of the whole year -- it can be surmised that larvae production, at least in 1970 and 1971, was below optimum. Furthermore, since the oysters on which Walne assessed fertility were probably in better condition than Clarinbridge oysters the estimates for larvae production at Clarinbridge given in Table 30 may be overestimates.

TABLE 31

DRY WEIGHT CONDITION INDICES OF CLARINBRIDGE OYSTERS DURING THE BREEDING SEASONS OF 1970 AND 1971

Month	1970	1971
May	97	117
June	116	129
July	108	110
August	127	116
September	103	139
MEAN	110	122

Predators and Competitors of Pelagic Larvae

"A great many marine animals that naturally feed on plankton organisms exact a very heavy toll of oyster larvae during the pelagic period." (Korringa, 1941). This submission, and the general classification of the types of animals which may prey on oyster larvae which followed, although of little practical value, illustrates the hazards which face oyster larvae during their time drifting in the sea.

Waugh (1957a) quoted Cerruti (1942) when stating that "enormous numbers (of larvae) must be lost during development as a result of predation by *Sagitta*, *Ascidiella*, *Ciona* and *Polydora*." He also cited observations made by Shelbourne who showed that *Aurelia aurita* and *Pleurobranchia pileus* consume vast quantities of larvae and are probably the most important predators in the Rivers Crouch and Roach. Orton (1926) suggested that mullet may also be serious pests of oyster larvae.

It is practically impossible to determine, in natural conditions, the effects of predators on bivalve larvae populations. However, casual observations at Clarinbridge of one known predator, *Aurelia aurita*, suggest that the destruction of larvae may have been severe at certain times of the breeding season. *Aurelia aurita* usually moved into shallow inshore waters around the Clarinbridge oyster bed in early June and it congregated in large numbers in mid or late July. In 1968 and 1969 large numbers of these jellyfish were observed in the area, but in 1971 considerably greater numbers arrived, with the assistance of the prevailing south-westerly winds. They were so dense as to become aggregated into 'rafts', many of which became stranded on the shore. The effect of these animals on the survival of oyster larvae cannot be quantified, but the low numbers recorded in June and July suggest a possible correlation.

Competition for food from more effective grazers may seriously jepardize the chances of oyster larvae developing to the eyed stage (Waugh, 1957a), firstly because they will not obtain sufficient food to grow and secondly, as Korringa (1941) points out, the slower their development the longer they must remain in the plankton and, therefore, their exposure to predators will be increased.

B. Spat Settlement

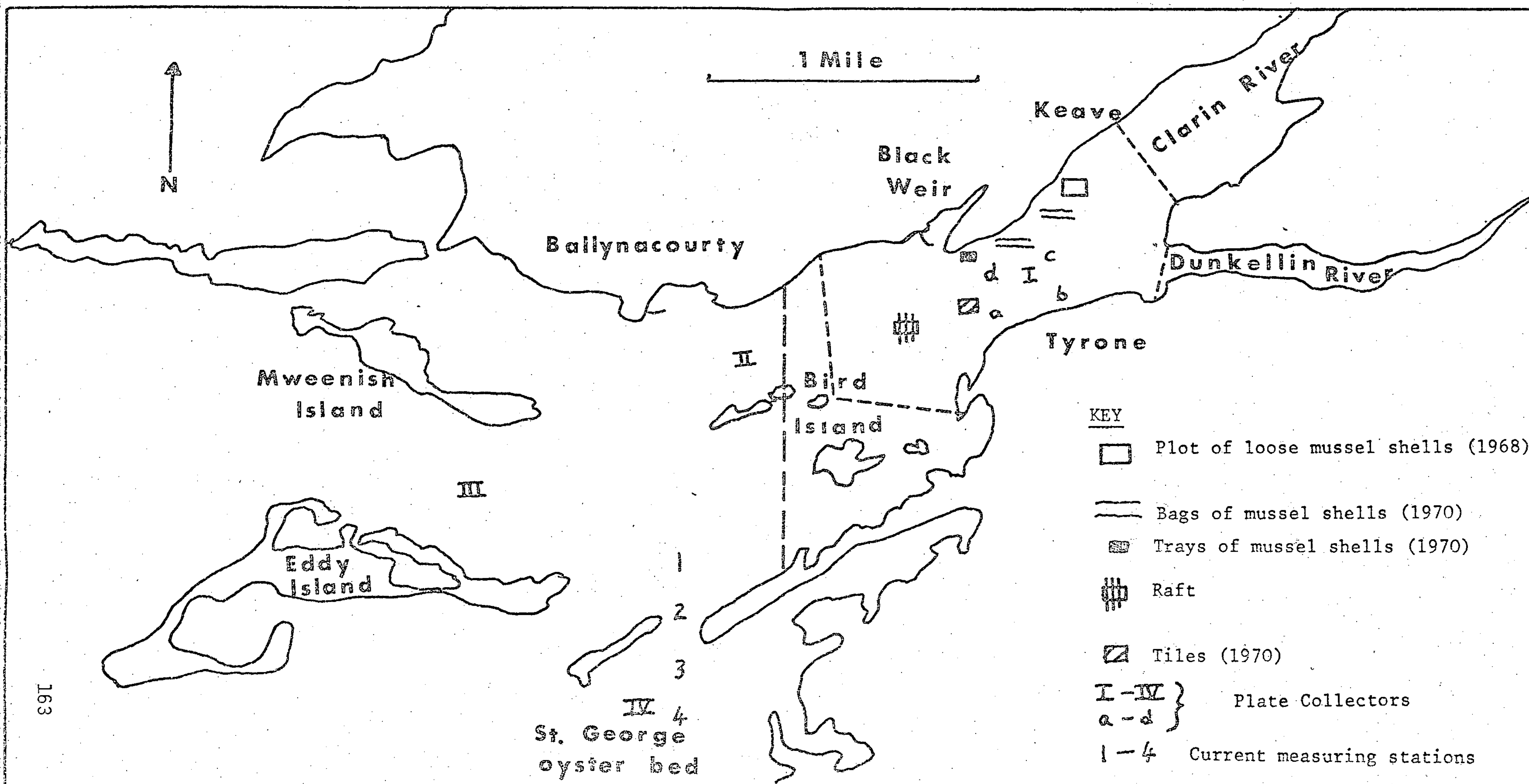
Oyster larvae will usually settle on any fairly clean, slightly roughened surfaces, such as shells of recently dead molluscs, rocks and suitable artefacts such as tiles and ironware which may be present in the water. Several types of natural and artificial spat collectors were employed to monitor spatfall in the current investigations. Some of the collectors were also used on a larger scale in an attempt to collect commercial quantities of spat; the results of these trials will be discussed in Chapter VII.

1. Unglazed Plates

Unglazed porcelain plates, each 17cm in diameter and supported on concrete blocks (Duggan, 1969), were distributed in pairs at the sampling stations shown in Map 6. Each pair of plates was held horizontally approximately 3cm above the surface of the concrete block. Since both sides of a plate could be colonized the effective area for settlement on each plate was approximately $227cm^2$.

The plates were employed mainly to determine the intensity and distribution of spat settlement on the oyster bed and in adjacent waters. One plate of each pair was examined (i.e., the newly settled spat were counted) and replaced by a clean plate every two or three days. The other plate was examined and returned to the block on each occasion. Using this procedure it was possible to determine, (a) exactly when spat settlement occurred (from the plates replaced periodically);

MAP 7. DISTRIBUTION OF SPAT COLLECTORS AND CURRENT MEASURING STATIONS



(b) how the numbers of spat and competing organisms built up during the breeding season, and (c) the growth and mortality rates of newly settled spat (from the permanent plates).

Plates were first distributed on June 21st, 1968; July 11th, 1969; June 24th, 1970, and June 9th, 1971. The plates were distributed well before the first spat settlement each season and in 1970 and 1971 the permanent plates were not taken up until settlement had ceased. During the period between placement and first spat settlement there was time for the development of a film of bacteria and other micro-organisms on the plates, which, according to some authorities (Cole and Knight-Jones, 1949) improves the surface for spat settlement. However, subsequent records of large spat settlements on plates which had been placed in the water for less than a day suggests that preconditioning of settlement surfaces may not be essential to ensure spat settlement.

The advantage of these plates in monitoring spatfall is that they are easy to handle and examine and spat contrast well with the white background. However, they present only a minute fraction of the total area available for spat settlement and thus, the information that can be gained is limited. Waugh (1957a) found the same problem when using slates as collectors. On one occasion he found that the block holding his slates had collected many more spat per unit area than the slates and for this reason their use was discontinued. Similar observations were made at Clarinbridge where plates on blocks placed several metres apart collected strikingly different numbers of spat. Despite these drawbacks plates provide useful data which can be compared between stations and between years if complete seasons' results are combined and interpreted with caution.

2. Mussel Shell

Mussel shells (*Mytilus edulis*), which have been used for large scale spat collection in Britain and Holland, were obtained from various mussel processing factories in Ireland and distributed over the study area in various ways in order to complement the information gained from unglazed plates.

(a) Mussel Shells in Netting Bags

In 1968, 15 wire netting bags, each containing approximately 5kg (about 600 single valves) of shells were placed on the seabed on July 10th at sites on the oyster fishery. This was sufficiently in advance of the first spat settlement to allow any chemical reactions between the netting and the sea water, which might inhibit settlement, to be completed. One hundred shells were examined for spat settlement on August 22nd.

In 1970, 48 plastic netting bags were each filled with approximately 10kg of shells. The bags were tied in trains of 6 and distributed as shown in Map 7. Samples of 100 shells from each train of bags were examined periodically until spring 1971.

No bags of mussel shells were distributed in 1969 or 1971.

(b) Loose Mussel Shells

On July 8th, 1968, approximately 5 tons of mussel shells were scattered over an acre plot marked out at Keave (Map 7). In 1969, 1970 and 1971, a further estimated 30 tons, 100 tons and 5 tons of mussel shells were scattered over the oyster beds by members of the Clarinbridge Oyster Development Committee, under the supervision of the author, as part of the oyster bed development programme (see later). In 1969, the bulk of the shell had been distributed by the end of July; in 1970 and 1971 distribution was completed during the second week of August.

Samples of loose mussel shells were examined for spat settlement periodically throughout the study period during routine dredge surveys on the oyster bed.

(c) Mussel Shells in Trays

In 1970, 10 trays constructed of wood and plastic netting bases (5ft x 2ft.6ins) were filled with shells and placed below low water mark on an area of flat ground at the northern margin of the oyster bed and to the east of Black Weir pier (Map 7). These shells soon became heavily silted and unsuitable for spat settlement, illustrating how important site selection is in the distribution of spat collectors. Similarly, mussel shells held in bags tended to become silted or choked with fouling materials which adhered to the bags. Thus, it would appear that, while it is difficult to recover any loosely distributed shell, the compensatory benefits gained from bagged shell laid on the seabed are only marginal, particularly on a public oyster fishery.

The advantage of using mussel shells to collect spat is that they disintegrate quite rapidly (in 2 to 3 years) leaving the attached spat free to grow into well shaped adults. This means that in both commercial oyster rearing and research labour is not wasted separating spat from the collectors.

3. <u>Oyster Shells</u>

During routine dredging surveys, oyster shells were examined for the presence of spat since these were probably the most abundant and most attractive natural settlement surfaces on the oyster bed.

4. <u>Cardboard Egg Trays</u>

In 1969, cardboard egg trays coated in a lime/cement mixture* (which have been employed by various workers in Europe and North America) were arranged in units consisting of two tiers, each with five trays, encased in wire netting. On August 8th, one unit was placed on the seabed at each of the plankton sampling stations shown in Map 6. The unit laid at Black Weir was examined on August 27th. The remainder were left for examination in the autumn. However, by the time it was possible to examine these collectors most of the trays had disintegrated, thus highlighting one of their disadvantages if they are not adequately prepared and properly handled. Had the trays been encased in stronger, fine mesh structures, the spat would have been retained after the cardboard had disintegrated.

In 1971, egg trays were employed on a large scale in an attempt to catch substantial numbers of spat. Approximately 2,000 trays were placed in plastic net bags and suspended from

* 2 parts lime/1 part cement, mixed with water to give a thin mixture. The trays are dipped, allowed to dry slowly to avoid cracking of the lime/cement coating. This procedure may be repeated 2 or 3 times and then the trays are allowed to dry, but prevented from drying too quickly by occasionally sprinkling them with water.

a raft anchored over the oyster bed. Single trays of bags were also suspended from buoys at the four plankton sampling stations in order to complement the information gained from the standard plate collectors.

5. Tiles

In 1970, approximately 800 rejected roofing tiles (flat and curved) were treated with a lime/cement mixture in the manner previously described. They were lashed in bundles of 5, each tile being separated from the next by a stone or a piece of broken tile to allow the passage of water between them. Three sets of tiles were placed in each of 24 galvanised wire trays (Plate 7). Twenty trays were arranged in 4 stacks in the centre of the oyster bed. The remaining 4 trays were placed at the plankton sampling stations on August 10th.

Twenty sets of tiles were placed near the trays of mussel shells mentioned previously. These tiles also became heavily silted and caught fewer spat than those placed elsewhere.

Whilst the tiles proved very effective for catching spat the labour involved in preparing and transporting them was considerable and their use on a large scale on a public fishery could not be contemplated. Furthermore, considerable labour would be required to detach the spat from the tiles - an obvious deterrent in both oyster farming and research.

6. Scallop Shells

In 1970, an attempt was made to assess the potential of 'off the bottom' spat collection using strings of scallop shells (Pecten maximus) suspended from a raft anchored over the oyster bed. Each string supported approximately 25 shells, with their inner surfaces facing downwards and with adjacent shells held apart by three-inch separators. The top shell was approximately 2ft below the water surface. Approximately 40 strings were attached to the underwater outriggers by divers. A number of the strings broke during the study period but sufficient remained to assess the value of scallop shells as collectors.

The greatest problem encountered with shells suspended in this way was the tangling of the strings. This made recovery of the shells difficult and diving amongst the strings hazardous. The problem could be solved either by weighting the strings or by suspending shells on stiff wire rather than nylon cord which was employed in these trials.

The raft was dragged from its moorings in a gale on 8th September and although many of the shells were recovered it was impossible to study the subsequent growth of spat off the bottom as had originally been planned.

7. P.V.C. Sheeting

In 1971, sheets of opaque, corrugated P.V.C. sheeting, approximately 70cm x 30cm, were tested as spat collectors, as a follow-up to Duggan's observations (pers. comm.) at the Tralee Bay Oyster Fishery where heavy spat settlements were recorded on similar material in 1969. Some sheets were roughened on one or both sides, others were painted on one or both sides and the remainder were untreated. The sheets were placed in plastic mesh bags and suspended from the raft anchored over the oyster bed.

RESULTS

1. Unglazed Plates

The numbers of spat which settled on temporary plates at each station during 1968, 1969, 1970, and 1971 are given in Tables 32a to 32d. The results for 1968 are of limited value because early identifications were uncertain and the investigations had to be terminated on August 22nd just as spatfall was apparently increasing.

Table 33 gives the accumulated numbers of spat which settled on permanent plates and the numbers of spat which remained when the blocks were taken up in September. The 1968 results were too unreliable to be included here.

Table 40 presents data on the settlement and survival of spat at Stations 1 and IV during 1971.

TABLE 32a.

SPAT SETTLEMENT ON TEMPORARY PLATES IN 1968

Station	I		II		III		IV		Total
Date	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	
29/7	0	0	1	0	1	0	9	0	11
5/8	2	0	2	0	2	0	6	0	12
12/8	0	0	0	0	1	0	0	1	2
19/8	0	0	0	0	0	0	0	0	0
22/8	0	0	0	0	0	0	0	0	0
Total	2	0	3	0	4	0	15	1	25

TABLE 32b

SPAT SETTLEMENT ON TEMPORARY PLATES IN 1969

Station	Ia		Ib		II		III		Total
Date	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	
24/7	21	0	0	3	0	1	1	3	29
28/7	50	20	22	1	17	6	0	0	116
7/8	146	20	0	0	0	0	0	0	166
11/8	72	32	0	7	--- Lost ---		34	14	159
18/8	24	3	21	1	-	-	3	0	52
21/8	3	0	1	0	-	-	1	0	5
26/8	26	10	0	0	-	-	15	6	57
29/8	4	0	0	0	-	-	--- Lost ---		4
1/9	2	0	0	0	-	-	-	-	2
4/9	14	0	0	0	-	-	-	-	14
Total	362	85	44	12	17	7	54	23	604
Average Daily Settlement	8.6	2.0	1.1	0.3	4.0	0.2	1.3	0.6	14.4

TABLE 32c.

SPAT SETTLEMENT ON TEMPORARY PLATES IN 1970

Station	I		II		III		IV		Total
Date	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	
31/7	0	0	0	0	0	0	0	0	0
4/8	0	0	0	0	0	0	0	0	0
7/8	5	3	0	0	0	0	1	4	13
11/8	15	15	2	0	1	0	20	8	61
17/8	12	42	14	1	0	0	47	16	132
20/8	31	2	2	0	0	0	18	14	67
24/8	47	60	5	4	0	0	0	0	116
28/8	230	185	12	8	0	0	42	34	511
3/9	6	4	4	14	1	0	27	14	70
11/9	2	0	2	0	2	0	10	6	22
15/9	0	0	1	0	0	0	3	1	5
Total	348	311	42	27	4	0	168	97	997
Average Daily Settlement	7.5	6.8	0.9	0.6	0.1	0	3.6	2.1	21.7

TABLE 32d.

SPAT SETTLEMENT ON TEMPORARY PLATES IN 1971

Station	Ia		Ib		Ic		Id		II		III		IV		Total
Station	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	
27/7	3	0	0	0	0	0	0	0	1	0	0	0	9	0	13
3/8	3	1	1	0	3	1	3	0	0	0	5	1	117	18	153
5/8	7	1	1	2	4	0	3	0	0	0	1	0	25	6	50
9/8	3	1	3	0	1	0	0	0	11	6	0	0	20	36	81
12/8	2	0	1	0	0	0	1	0	0	0	0	0	2	5	11
16/8	8	1	12	1	3	0	0	0	4	0	2	1	9	4	45
19/8	0	0	6	1	0	0	0	0	0	0	0	0	4	1	12
Total	26	4	24	4	11	1	7	0	16	6	8	2	186	70	365
Average Daily Settlement	1.1	0.2	1.0	0.2	0.5	0.04	0.3	0	0.7	0.3	0.4	0.1	8.0	3.0	15.9

2. Mussel Shells

The intensity of spat settlement on relaid mussel shells in 1968 and 1970 is given in Table 34. In each case 100 randomly selected single valves were examined. Oyster spat were found only on the inner shell surfaces, unlike *Anomia* spat which occurred on both surfaces.

Shells laid in the trays were examined on January 29th, 1971; they were heavily silted and only 3 spat were observed on 200 single valves. On the same day, however, 100 single valves dredged up on the oyster bed yielded 5 spat.

3. Oyster Shells

Table 35 illustrates the intensity of spat settlement on naturally occurring oyster shells. The figures presented were obtained on August 26th, 1969.

All the newly settled spat were observed on the inner surfaces of the shells. However, spat will settle on the outer surfaces, particularly of live oysters, and in 1971, the author counted as many as 58 spat attached to oysters taken from the Tralee Bay Oyster Fishery.

4. Cardboard Egg Trays

Table 36 presents the numbers of spat collected on one unit of egg trays placed at Station I on August 8th, 1969 and retrieved on August 27th. The trays placed at other stations broke up before they could be examined in the autumn and, therefore, figures to complement those in Table 36 are not available.

In 1971 the mean number of spat observed on egg trays suspended from a raft anchored over the oyster bed was only 1.1. Spat were absent from the majority of trays on September 23rd and no significant results can be presented for that year.

TABLE 33.

SPAT SETTLEMENT ON PERMANENT PLATES IN 1969, 1970 AND 1971

Station		I	II	III	IV	Total	Average Settlement per Day per Station[2]
1969	Acc. Total	417	40	75	-	532	5.0
	Final Total[1]	130 (31%)	36 (90%)	56 (75%)	-	222(42%)	2.1
1970	Acc. Total	297	76	0	149	522	3.7
	Final Total	3 (1%)	38 (50%)	0	12 (8%)	53(10%)	0.3
1971	Acc. Total	49	20	17	254	340	2.4
	Final Total	5 (10%)	3 (15%)	7 (41%)	48 (19%)	63(19%)	0.5

1. September 15
2. A standard period of 35 days available for spat settlement.

TABLE 34.

SPAT SETTLEMENT PER 100 MUSSEL SHELLS IN 1968 AND 1970

State of Mussel Shells	1968				1970			
	Date	Station	No. Shells With Spat	No. Spat	Date	Station	No. Shells With Spat	No. Spat
Loose on Seabed	22/8	I	17	19	8/10	Ia	12	16
						Ib	16	20
In Bags	21/11	Ia	2	4	22/8	Ia	2	2
		Ib	8	13	23/9	Ib	18	24
		II	1	1		II	0	0
		III	1	2		III	0	0
		IV	Lost			IV	24	47
In Trays					16/9	I	1	1

TABLE 35.

SPAT SETTLEMENT ON OYSTER SHELLS

	Numbers of Spat	
Shell	Right Valve (flat)	Left Valve
1	10	23
2	5	2
3	30	43
4	16	16
5	0	38
6	7	0
7	0	4

TABLE 36.

SPAT SETTLEMENT ON EGG TRAYS IN 1968

Tray	Number of Spat	
1	$\frac{420}{100}$	$\frac{500}{150}$
2	$\frac{135}{50}$	$\frac{200}{82}$
3	$\frac{172}{80}$	$\frac{172}{186}$
4	$\frac{146}{20}$	$\frac{215}{120}$
5	$\frac{186}{40}$	$\frac{150}{50}$
Average number per tray	322.4	

The upper figure is the number of spat on the upper surface on the tray.

TABLE 37a.

SPAT SETTLEMENT ON TILES IN 1970

	Station I				
Crate / Tile	Top	2	3	4	5
Top	$\frac{0}{55}$	$\frac{57}{13}$	$\frac{58}{25}$	$\frac{208}{47}$	$\frac{158}{77}$
B	$\frac{25}{27}$	$\frac{79}{70}$	$\frac{120}{25}$	$\frac{90}{49}$	$\frac{217}{23}$
C	$\frac{4}{35}$	$\frac{70}{50}$	$\frac{64}{11}$	$\frac{48}{39}$	$\frac{167}{23}$
D	$\frac{25}{27}$	$\frac{48}{55}$	$\frac{35}{20}$	$\frac{23}{78}$	$\frac{104}{85}$
E	$\frac{12}{20}$		$\frac{23}{35}$	$\frac{38}{49}$	$\frac{88}{115}$

TABLE 37b.

SPAT SETTLEMENT ON TILES IN 1970

Crate / Tile	Station I					Station IV
	Top	2	3	4	5	
Top	190/70	190/70	210/40	4/-a	70/48b	180/90
B	120/45	120/65	60/30	27b/20	100/25	150/100
C	20a/20	100/30	70/30	25b/60	60/45	100/120
D	30/22	75/35	65/55	68/35	65/30	100/40
E	60/25a	70/55	115/55	25b/50	20/60	15/30

a -- heavily silted
b -- heavily fouled with algae

5. Tiles

Tables 37a and 37b present the numbers of spat which settled on a column of tiles placed at the centre of the oyster bed on August 10th, 1970. The tiles were examined on September 16th (a) and October 14th (b).

A set of 4 tiles recovered from the oyster bed on January 12th, 1971, harboured an average of 70 spat and a set of 5 tiles recovered on February 25th, 1971, held an average of 144 spat each.

6. Scallop Shells

The numbers of spat attached to scallop shells which were salvaged after the raft had gone adrift on September 8th are given in Table 38.

The majority of spat on strings A,C and D occurred on the smooth inner surfaces of the shells which had been facing downwards. On string B, where curved shells were employed, spat were distributed approximately evenly between the two surfaces.

The maximum settlement recorded on a single shell was 270 spat, which was 10 more than the highest number observed on a tile in 1970 but only about half the maximum recorded on an egg tray in 1968.

7. P.V.C. Sheeting

Only one oyster spat recorded on P.V.C. sheeting, although barnacles and *Anomia* sp. spat were common.

TABLE 38

SPAT SETTLEMENT ON SCALLOP SHELLS[1] IN 1971

Shell	String A[2]	String B[3]	String C[2]	String D[2]
Top	13	157	0	0
2	26	270	0	62
3	19	185	2	0
4	16	51	22	0
5	6	20	15	25
6	18	145	35	32
7	12	98	23	0
8	7	43	42	69
9	7	96	22	5
10	14	0	100	0
11	15	0	26	16
12	10	0	20	0
13	3	0	0	0
14	15	0	0	0
15	10	0	0	0

1 - both surfaces
2 - flat shells
3 - curved shells

DISCUSSION

Initial Settlement

It can be inferred from the four years observations presented earlier that spat settlement at Clarinbridge usually commences during the last week of July. This is about three weeks later than it generally starts in Holland (Korringa, 1941), Essex (Waugh, 1957a) and Morbihan (Marteil, 1960).

Duration and Intensity of Spat Settlement

Spat settlement had generally ceased at Clarinbridge by mid-September, although eyed larvae were occasionally still present in the water. This indicated a maximum effective spat settlement period of approximately six weeks.

In Holland spatfall generally ceased in about mid-August, again after a period of approximately six weeks (Korringa, 1941). Waugh (1957a) observed a similar pattern in Essex where spatfall lasted from early June to mid-July in 1950 and from early July to mid-August in 1953. Marteil (1960) mentioned that larvae may mature and settle in September at Morbihan, but since peak spawning occurred in June it is presumed that most settlements were completed much earlier than at Clarinbridge, probably during a period similar to that observed elsewhere (six weeks).

Thus it appears that the duration of spat settlement was fairly constant at approximately six weeks, or slightly longer in better seasons. However, as Waugh has shown, the exact period of settlement may vary from year to year, being earlier in years when the breeding cycle is accelerated by warmer conditions.

Tables 32a to 32d show that maximum settlement took place at Clarinbridge during August, again about three weeks later than at the oyster beds mentioned above.

Settlement intensity varied from station to station and between adjacent collectors. However, all the data presented point to the fact that maximum settlement occurs on the oyster bed and that settlement decreased with distance from the oyster bed. The one apparent anomaly in the Clarinbridge results was the regular, relatively heavy spat settlement which occurred at Station IV, which is remote from large stocks of breeding oysters. Larvae may have reached this area from the Clarinbridge oyster beds, from relatively small stocks of adult oysters in Brandy Harbour and on the St. George oyster bed or from an oyster population in Kinvara Bay to the south. When they reached the area they were trapped as a result of hydrographic conditions which are as yet little understood.

Table 39 presents current measurements made on a spring tide on July 10th, 1971, at points near Station IV. The sampling stations are shown on Map 7. The current speeds were very low compared with those recorded at Stations I and III a few days earlier (Chapter III, p73) when there were weaker spring tides. Further, it would appear that there were nearly 3 hours of slack water around high tide, which would have allowed more time for spat settlement than in other areas if, as has been suggested (Orton, 1937a; Korringa, 1941; Marteil, 1960), spat settlement tends to occur at slack water. However, further observations are required to establish the exact reasons for the consistently high settlement rates at Station IV.

TABLE 39.

TIDAL CURRENTS AT STATION IV

Station	I		2		3		4	
Time	Vel.[1]	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.
1400	0.1	E	0.2	N	0.1	E	0.2	E
1500	< 0.1	E	0.3	NE	0.2	E	0.2	E
1600	< 0.1	E	0.1	NE	0.2	NE	0.1	NE
1700	-	-	-	-	-	-	-	-
1800	< 0.1	W	-	-	0.1	N	-	-
1900	-	-	-	-	-	-	0.1	NW
2000	-	-	-	-	-	-	0.1	NW

High water 1746.
(1) Knots

During the period of investigation, spat settlement was heaviest in 1969. In that year also, larvae production and the numbers of larvae reaching the eyed stage were at a peak. The size of the 1969 settlement is not evident from the results of spat counts on the temporary plates; using these results as a basis for comparison 1970 would have been the year of maximum settlement. However, it will be noted in Table 33, which presents the spat counts made on the permanent plates, that spat mortality was considerably lower in 1969 than in 1970 or 1971. Table 33 also shows that the average spat settlement per station over a standard period of 35 days was, again, highest in 1969. Furthermore, subsequent population surveys (Chapter V) have shown that the 1969 settlement produced the strongest year class to emerge between 1968 and 1972. Duggan (pers. comm.) also recorded a large settlement in 1969 in Tralee Bay.

Distribution of Spat Settlement

The majority of spat tend to settle in areas where other oysters are present. Three hypotheses have been advanced to explain this phenomenon: (1) negligible movement of larvae away from their source of origin; (2) oyster beds may occur where there are natural larva traps produced by specific hydrographic conditions (e.g., in eddies - Orton, 1937a; Shelbourne, 1957); and (3) larvae may be stimulated to settle by pheromones emitted from adult oysters on the main oyster bed (Hidu, 1969).

At Clarinbridge it is clear from current measurements that hypothesis (1) above does not explain why maximum spat settlement occurred on the oyster bed. Point (2) helps to explain the anomalous, heavy settlements at Station IV where there were few adult oysters, but it does not entirely explain why heavy settlement occurred at Station I on the oyster bed because this area is subject to hydrographic conditions which are somewhat similar to those in areas to the west which are devoid of oysters.

It has been shown in the laboratory (Hidu, 1969) that larvae settle in response to pheromones emitted by post-metamorphic oysters and perhaps also in response to oyster shell protein (Crisp, 1967). Such chemically induced settlement has not yet been demonstrated in nature although gregarious settlement has been observed in several species. Knight-Jones (1952) recorded gregarious settlement in oyster larvae on Essex oyster beds where he found between 2 and 22 spat per 10 shells amongst oysters and between 2 and 8 spat per 10 shells in unstocked areas in 1948.

Hidu (1969) showed that initial settlement is spontaneous, but that as it proceeds the presence of new spat stimulates more larvae to settle at or near the same site. If that was the case in nature it would be expected that more larvae would have settled on the permanent plates than on the temporary plates at Clarinbridge. In fact the reverse was the case in 1969 and 1970 when considerably more larvae settled on the temporary plates. This may have been due to the fouling of the permanent plates which increased as the season progressed or, alternatively, gregarious settlement on the temporary plates might possibly have been induced by the presence of spat on the adjacent permanent plates.

If gregarious settlement does occur in nature, as Knight-Jones suggests, it would be an obvious advantage in the maintenance of a dense population, which is necessary for successful breeding. This would be the case particularly in years of meagre larvae production when it would be necessary for the majority of mature larvae to settle on the oyster bed in order to maintain the population. In years when large numbers of mature larvae are produced settlement may increase in areas distant from the oyster bed. This appears to have happened in 1969 at Station III where settlement occurred despite the absence of adult stocks in the area.

In emphasising the probable importance of gregarious settlement Knight-Jones (1952) eliminated the possibility that intrinsic environmental differences caused the variations in settlement intensity between stocked and unstocked areas. However, the observations made at Station IV suggest that gregariousness induced by the presence of other oysters is not an essential prerequisite for heavy settlement since specific hydrographic conditions, such as eddies, or relatively slow water movements such as those observed at Station IV, can induce settlement in areas devoid of adult oysters.

Vertical Distribution of Spat Settlement

Korringa (1941) found that, contrary to the observations of several other workers, the majority of larvae in the Oosterschelde settled near the seabed as a result, he suggested, of the reduced current in the lower water strata. Cole and Knight-Jones (1939) found that in tanks, where lateral water currents were negligible, spat settlement was greatest near the surface but in their field experiments in the Helford River they observed greatest settlement near the bottom (Cole and Knight-Jones, 1949).

Spat settlement was recorded on towers of tiles, approximately 5ft. high, situated on the Clarinbridge oyster bed. The results in Tables 37a and 37b present little evidence to suggest that the level of settlement could be ascribed to intrinsic behaviour of the larvae. Spat counts were generally lower on the undersides of tiles and on the lower tiles because they were heavily silted. It is not known whether the silting prevented settlement or subsequently smothered spat. Similarly, the intensity of settlement on strings of scallop shells, illustrated in Table 38, gives no clear indication of the stratification which might be expected if larvae tended to settle more frequently near the surface.

The main point illustrated by these results and those of Korringa is that in order to obtain maximum spat settlement, spat collectors must be sited where slow currents prevail and in such a way so as to reduce silting and fouling.

It is pertinent to note that the majority of spat collected on tiles and egg trays at Clarinbridge were recorded on the upper surfaces. Cranfield (1968) noted that larvae of O.lutaria tended to settle on the upper surfaces of collectors and Korringa (1941) noticed the same behaviour in O.edulis in the Oosterschelde, again, contrary to the observations of several workers, including Cole and Knight-Jones (1939). Korringa attributed the differences in settlement distribution to "discriminating selection on the part of the larvae." This author suggests that such discrimination on the part of the oyster larvae is not confirmed by the information collected at Clarinbridge. Whilst the majority of larvae recorded on tiles and egg trays were on the upper surfaces, probably as a result of excessive silting of the lower surfaces, the majority of spat recorded on plates and scallop shells occurred on the lower surfaces. This indicates that the nature and the position of the spat collectors may have as great an influence on the distribution of settlement as the behaviour of the larvae.

Spat Survival and Growth

Table 33 indicates that by mid-September 1969, 42% of the spat which settled on permanent plates had survived. In 1970 and 1971 survival was considerably lower, being 10% and 19% respectively. The 1969 figure is similar to that recorded by Waugh (1957a) one month after the major settlement in Essex in 1952. The latter figures correspond with the 10% survival rate estimated by Knight-Jones from observations made in 1948. The Clarinbridge survival rates, which were determined from a series of observations, rather than from only two observations made by Waugh and Knight-Jones, present at least a partial explanation for the large recruitment of 1969 spat into the adult stocks. The low initial survival rates in 1970 and 1971, coupled with the smaller production of mature larvae in those years, explains the low recruitment rates which were observed subsequently (see later).

Table 40 details the spat settlement and survival at Stations I and IV in 1971. By mid-September in 1970 and 1971, spat, which were approximately 0.3mm at settlement, at Station I had attained a mean size of 1.7mm. The modal size was 1.5mm and the maximum 5.0mm. In contrast, at Station IV in 1971, where the initial major settlement had occurred in early August, the spat had attained a mean size of 4.0mm.

The growth of 1970 spat was monitored until May 1972 and will be discussed in Chapter V.

TABLE 40.

SPAT SETTLEMENT AND SURVIVAL AT CLARINBRIDGE IN 1971

Station	I			IV		
Date	New	Old	Total	New	Old	Total
27/7	-	-	-	4	-	4
3/8	-	-	-	135	-	135
5/8	-	-	-	174[i]	-	174
9/8	14	-	14	9	156	165
12/8	5	11	16	26	111	137
16/8	12	7	19	27	104	131
19/8	-	12	12	4	104	108
23/8	-	10	10	-	95	95
27/8	-	8	8	-	82	82
2/9	-	6	6	-	67	67
8/9	-	5	5	-	58	58
14/9	-	5	5	-	48	48
17/9	-	5	5	-	48	48
30/9	-	4	4	-	40	40
15/11	-	1	1	-	11	11

i - new plate.

Settlement on the Seabed

Settlement on natural collectors lying on the seabed was difficult to assess quantitatively because of their variety and distribution. Recently dead oyster shells were the most obvious natural settlement surfaces at Clarinbridge. However, surveys of large spat and small brood oysters showed that spat also settled on live adult oysters, other spat, rocks, shells of clams, *Anomia* and whelks but not on shell of *Chlamys* spp. The latter observation is in common with that of Cole and Knight-

Jones (1939) who stated then that in spite of their abundance *Chlamys* shells were unattractive to oyster spat. However, Cole and Knight-Jones (1949) later found *Chlamys* shells to be equally attractive to spat as oyster shells.

Examination of relaid mussel shells produced poor results. The largest percentage of shells carrying spat in any year was 20%. Generally, however, less than 10% of the shells examined carried one or more spat (Table 34). The effectiveness of the shell could be increased if it was ensured that the valves or at least pairs of valves, were distributed separately and evenly over firm seabed where they would not become buried or heavily silted.

Competitors and Fouling Organisms

Throughout the oyster's breeding season many other organisms compete for vacant settling spaces on the oyster bed. Amongst the more conspicuous competitors at Clarinbridge were the tube-worm *Pomatoceros triqueter*, the barnacle *Balanus balanoides*, the sea-squirt *Ciona intestinalis* and the spawn of *Gobius* sp. Unidentified bryozoans and several species of algae were prominent amongst the fouling organisms, particularly on the upper surfaces of plates and tiles.

Sea-squirts were a particular problem on spat collectors because they grew rapidly, smothering spat and preventing further settlement both directly, and indirectly by encouraging the deposition of silt. They were particularly abundant at Stations III and IV where permanent plates were usually completely covered by mid-August.

Pomatoceros and *Balanus*, whilst common on all types of spat collector at all stations, did not pose such a threat to oyster settlement because they did not cover large areas as quickly as sea-squirts. These species usually occurred on the under surfaces of plates and tiles and they generally outnumbered oyster spat on the latter.

During the first half of the breeding season, Goby spawn was deposited regularly on the undersides of plates and on the upper surfaces of supporting blocks. On several occasions up to 80% of the underside of a plate was covered with spawn which effectively prevented the settlement of other species, even after the young gobies had hatched.

CHAPTER V

POPULATION STUDIES

V. POPULATION STUDIES

The management of an oyster fishery can be satisfactorily planned only if the basic mechanisms governing the functioning of the oyster population are known and fully understood. In this chapter data relating to the population dynamics, growth, mortality, conditions and production of the Clarinbridge oyster population are presented as a basis for the management proposals which will be detailed in Chapter VII.

I. The Extent of the Oyster Grounds

The extent of the Clarinbridge oyster grounds is illustrated in Map 4 (Chapter III). The limits of the grounds were determined by a combination of observations based on:

(i) dredging,

(ii) grabbing,

(iii) direct observations by diving.

For the purposes of this work the productive area of the fishery was taken to be 110 hectares (=1,000,000 square metres or approximately 264 acres). The eastern and western limits of the grounds are characterised by a gradual change in the composition of the substrate from sand and fragmented shell overlying mud to soft mud, which is unsuitable for the settlement or survival of oysters. A further limiting factor at the eastern boundary is inadequate salinity at certain times of the year (see Chapter III). The northern and southern margins of the grounds are defined by the low water spring tide mark or by the boundary between suitable and inhospitable substrate types, such as occurs in Tyrone Bay, near the south shore.

The oyster bed is virtually a discreet unit, the only possible continuity with the neighbouring private St. George fishery being (a) through the channel to the south of Bird Island; (b) by virtue of the pelagic larval phase which may lead to some interchange between the neighbouring areas.

2. Population Density and Size

Very few attempts have been made to determine the density of oysters in wild populations, let alone the absolute size of the populations. This is partly because most oysters research has been carried out on cultivated grounds where population densities are known and partly because of the practical difficulty of sampling the population accurately.

To estimate the size of the semi-cultivated oyster populations in the Rivers Crouch and Roach, Essex, Shelbourne (1957) used a specially deisgned dredge (with an attached pedometer) which was calibrated by comparing its efficiency with that of a 100% efficient Petersen grab. He presented the densities and total numbers for each of 18 sampling sectors covering a total of 13½ million square yards (approximately 2,800 acres) but he did not present fiducial intervals for his estimates.

Cranfield (1968a) made estimates of the density of oysters (Ostrea lutaria) in a wild population in Foveaux Strait, New Zealand, based on the direct observations of divers. He pointed out that it was difficult to observe oysters of less than 35mm in diameter and so his estimates omit what might be expected to be a large proportion of the population. Cranfield made no attempt to convert his density values to total population densities or to estimates of the commercial stock (oysters exceeding 54mm in diameter) present on the grounds.

In the present study several attempts were made to estimate the size of the Clarinbridge oyster population in order to (i) provide an estimate of the numbers which are supported in the prevailing conditions; (ii) to determine the standing crop; (iii) to determine the commercial stocks available for fishing in 1970 and 1971; (iv) to investigate the effects of fishing on the stocks.

(a) Methods

Three methods for sampling the oyster population were available to the author - (i) dredging; (ii) direct observation by diving; (iii) grabbing.

(i) Dredging - this is an inefficient method (5-20% efficient; Key, pers. comm.) for collecting oysters and results vary according to the nature of the seabed; the state of the sea and the technique of the operator.

(ii) Direct observation by diving - this method is costly and time-consuming. It is extremely difficult to observe all the oysters in a particular area of the seabed because (1) they tend to be hidden amongst rocks, shells or seaweeds; (2) they tend to merge in with the background and (3) any attempt by the diver to move material on the seabed results in a disturbance of the substrate which immediately reduces the visibility.

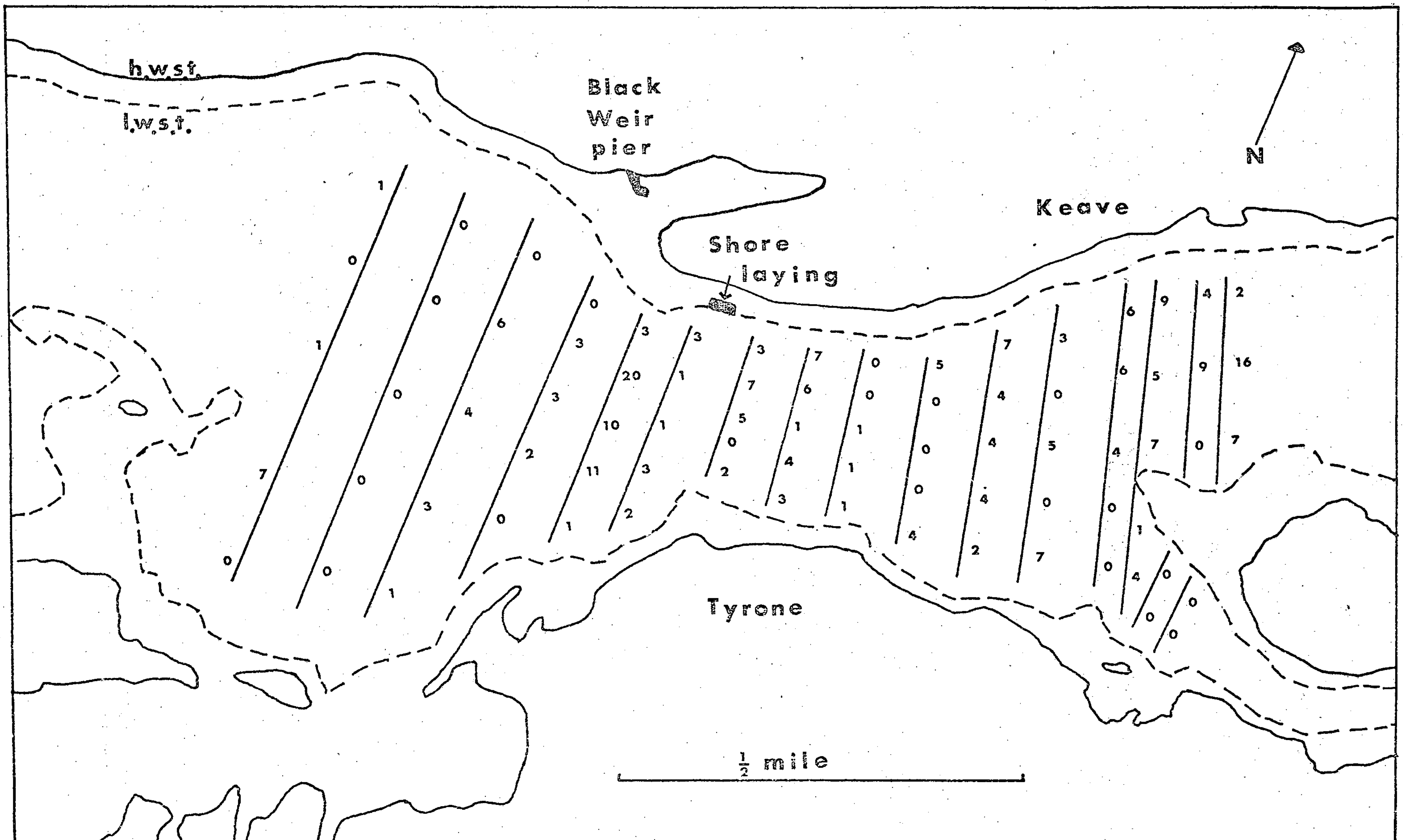
(iii) Grabbing - a variety of grabs have been developed to sample benthic epifauna. In good conditions most of these grabs take 100% samples, but generally they can sample only small areas (1/10 - 1/5m^2). In spite of the latter disadvantage a 1/10m^2 Baird grab (based on Baird 1958a), which had been designed specifically for sampling the epifauna of oyster beds, was selected for the Clarinbridge survey.

Survey Procedure

Four hundred grab samples were taken at 80 stations which were situated on the 16N-S transects shown on Map 8. The boat was anchored at each station and five grab samples were taken. Repeated sampling on the same spot was avoided by the slight movement of the boat with the tide and by taking the samples from different points on the boat. All oysters in each sample were counted and measured to the mearest millimetre. Foul hauls were repeated.

The surveys were carried out at times of low water neap tides when tidal currents were at a minimum. This ensured that the grab could be seen to operate correctly and that material was not washed out of the grab while it was being hand hauled. Underwater observations confirmed that the grab took 100% samples to a depth of 7 cm in the major substrate types present on the oyster grounds.

MAP 8. GRAB SAMPLING STATIONS AND THE DENSITIES ($/\frac{1}{2}m^2$) AND DISTRIBUTION OF OYSTERS IN NOVEMBER 1971



(b) Results

Table 41 shows the mean density of oysters recorded during the five population surveys carried out at the Clarinbridge Public Oyster Fishery. The total estimated populations on 110 hectares of oyster ground are given in the same table and the numbers of commercial size oysters (those exceeding 76mm in maximum diameter) are also presented. The oyster landings for 1970 and 1971 are also given and these will be compared with the observed changes in the commercial stocks during those fishing seasons.

Estimates of the numbers of grab samples required to give successively more precise population estimates are given in Table 42.

(c) Discussion

The mean density of oysters appears to have fluctuated between extremes of 6.3 and 9.0 per square metre between August 1969 and January 1972. Correspondingly the total population has fluctuated between 6,930,000 and 9,900,000. These apparent changes may have been due to a combination of factors which will be discussed in later sections.

The mean densities recorded at Clarinbridge are considerably higher than those presented by Shelbourne (1957) for the River Crouch (1.7 per square yard) and the River Roach (2.8 per square yard). He calculated from these estimates that there were $18\frac{1}{2}$ million oysters (15 million one-year olds plus $3\frac{1}{2}$ million breeding stock) in the Crouch and 7-1/4 million ($2\frac{1}{2}$ million one-year olds plus $4\frac{3}{4}$ million spawning stock) in the Roach.

TABLE 41

OYSTER POPULATION ESTIMATES AT THE CLARINBRIDGE PUBLIC OYSTER FISHERY - 1969 TO 1972 (1)

Date	August 1969	November 1970	April 1971	November 1971	January 1972
Mean density per m	6.4 ± 1.0(2)	9.0 ± 1.6	7.7 ± 1.1	6.3 ± 1.2	8.0 ± 1.6
Mean Population Size	7,040,000	9,900,000	8,470,000	6,930,000	8,800,000
Range^2	5,969,920- 8,110,080	8,137,800- 11,662,200	7,326,550- 9,613,450	5,610,000- 8,250,000	7,007,000- 10,954,900
Total No. 76mm+	627,968	538,560	470,932	604,989	495,000
Range	529,848- 726,008	442,816- 634,304	403,656- 538,208	489,753- 720,225	396,000- 594,000
Landings			560,000		268,000

(1) These results are derived from raw data which is filed with the author.

(2) 95% fiducial limits

Cranfield (1968a) found a mean density of oysters exceeding 35mm in diameter of 23.4 per square metre, with commercial oysters occurring at a density of 17 per square metre (it may be noted that the grounds had not been fished for several years at the time of the survey, thus explaining the relatively high density of commercial oysters). In contrast the density of commercial oysters on the Clarinbridge grounds fluctuated between 0.4 per square metre and 0.6 per square metre during the study period.

Shelbourne (1957) did not indicate the maximum density of oysters encountered on the Essex grounds. Cranfield (1968a), however, recorded densities of 35mm+ oysters in excess of 120 per square metre, in contrast to the maximum of 56 per square metre recorded at Clarinbridge, inclusive of all but the smallest size classes (1 - 10mm).

The population estimates presented earlier are based on the mean densities calculated from the 400 systematically collected grab samples. Reference to Map 8, however, shows that densities vary strikingly within short distances and that large areas (e.g., to the west of Black Weir pier) support low densities. This suggests, particularly in the light of the more intensive sampling carried out on the more densely populated areas of the fishery, that the population estimates may be too high. However, in view of the wide fiducial intervals (up to ±1,760,000) for the population means it is felt that the results presented are adequate for the current level of management practised at the fishery. Furthermore, it has been calculated [1] that in order to reduce the

---

(1) $$n = \frac{1.96^{*} \times \text{Standard deviation}}{\text{Required standard error}}$$ *95% fiducial limits

n=required number of grab samples, with ∞ degrees of freedom.

deviation about the mean to ± 550,000 (± 0.5 oysters per square metre or ± 0.03 to ± 0.05 commercial oysters per square metre) up to 31,000 grab samples would be required. Since effective grab sampling was carried out at a rate of only 100 grab samples per day, sampling on the scale mentioned above would take nearly one year to complete, and could not, therefore, be contemplated. (On the same basis a reduction of the deviation to ± 100,000 would necessitate the taking of over 400,000 grab samples.)

At the current level of sampling the deviation about the mean number of commercial oysters on the fishery prior to the fishing season was approximately ±20% and equivalent to good catches (approximately 6,000 oysters) taken by 16 to 20 boats. At the ± 550,000 level the deviation would be reduced to ± 5 to 8 boats' catches (Table 42) and at the ± 110,000 level a deviation of approximately ± one boat's catch would be obtained.

TABLE 42

NUMBER OF SAMPLES REQUIRED TO GIVE A DEVIATION OF ± 550,000 ABOUT THE POPULATION MEAN

Date	No. of samples required	Deviation -- Commercial oysters	Equivalent to n catches of 6,000
August 1969	14,186	± 49,060	8
November 1970	30,587	± 29,920	5
April 1971	14,914	± 30,580	5
November 1971	8,320	± 48,015	8
January 1972	15,098	± 31,020	5

It would be desirable to reduce the estimate of available stock to a value of 5 boats' catches (approximately 10% of the number of boats engaged in the fishery) but as it has been shown this is not a practical proposition unless several grabs could be employed simultaneously in the survey.

The estimate of the commercial stock available for fishing in 1970 (538,560) was close to the estimated numbers landed (560,000). However, the estimate made in April 1971 (470,932) indicated discrepancies in one or both of the earlier figures or more likely discrepancies in all three estimates. Likewise, the figures for the 1971 fishery (604,939; 268,000; 495,000 respectively) also show large discrepancies. These discrepancies can be partially explained by:

(i) the inaccuracy of the surveys resulting from the small numbers of samples taken;

(ii) the removal of sub-legal size oysters from the fishery - this is known to occur but the scale of the activity is unknown;

(iii) a stirring of the seabed by dredging with the consequent exposure and burying of oysters;

(iv) the horizontal redistribution of oysters as a result of fishing activities;

(v) the fact that the data were not transformed to account for the contagious dispersion of the stocks.*

*The variance of each population estimate was considerably higher than its corresponding mean indicating a departure from the normal distribution (i.e., contagion) assumed in the calculation of the population sizes.

(d) A Mark and Recapture Experiment

It was planned originally to estimate the size of the commercial stocks using a mark and recapture technique. Marked oysters were to be planted prior to the fishing season and recovered from the fisheries during December.

However, trials with a variety of marks proved unsuccessful and the plan had to be abandoned. For example, marine undercoat paint was applied to well-dried oyster shells. This was allowed to dry for as long as possible (i.e., until it was necessary to replace the oysters in the water. One sample was relaid in a littoral oyster holding tank and the other was placed on a marked area of the oyster bed. Within two weeks most of the paint had come off the tank oysters and only a small fraction of the oysters relaid on the seabed could be identified.

A further trial using numbered brass tags attached to the right valve by means of "Isopon" resulted in 79% of a trial batch of 100 oysters losing their tags within 10 months of laying in trays at L.W.S.T. level.

3. Population Structure

(a) Methods

Samples of approximately 500 oysters were collected by dredging at monthly intervals between February 1970 and July 1972. Dredge hauls were made on all parts of the oyster bed and all oysters were collected from each haul. The broadest diameter of each oyster was measured to the nearest millimetre[1]. Apparently there was no selection for size by the dredge in the size classes greater than 15mm in diameter. The absence of the smaller groups from the histograms reflects the difficulty of seeing them in the dredged material rather than their absence from the population. Comparative data (not presented) collected during the grab surveys discussed earlier, confirmed the absence of selection for size by the dredge.

(b) Results

Percentage size frequency histograms for 5mm size classes were plotted for each month of the study period. However, since changes in the size frequency peaks were slow only selected distributions have been presented in Figure 10 to illustrate more clearly the changes in population structure. The results of the August 1969 grab survey are also included in Figure 10 which indicates the changes in population structure over a period of three years.

The percentage size frequency distributions were converted to percentage weight frequency distributions (Figure 11) by multiplying the percentage in each size class by the mean weight of that class, which was estimated from the length-weight regression line presented in the next section.

Oysters measuring less than 10mm in diameter were rarely detected in the dredge samples although they did exist

(1) Monthly size frequency histograms, using 1mm size classes, were plotted from this data and are filed with the author.

FIGURE 10

CHANGES IN THE PERCENTAGE SIZE FREQUENCY DISTRIBUTION OF THE CLARINBRIDGE OYSTER POPULATION BETWEEN AUGUST 1969 AND JULY 1972.

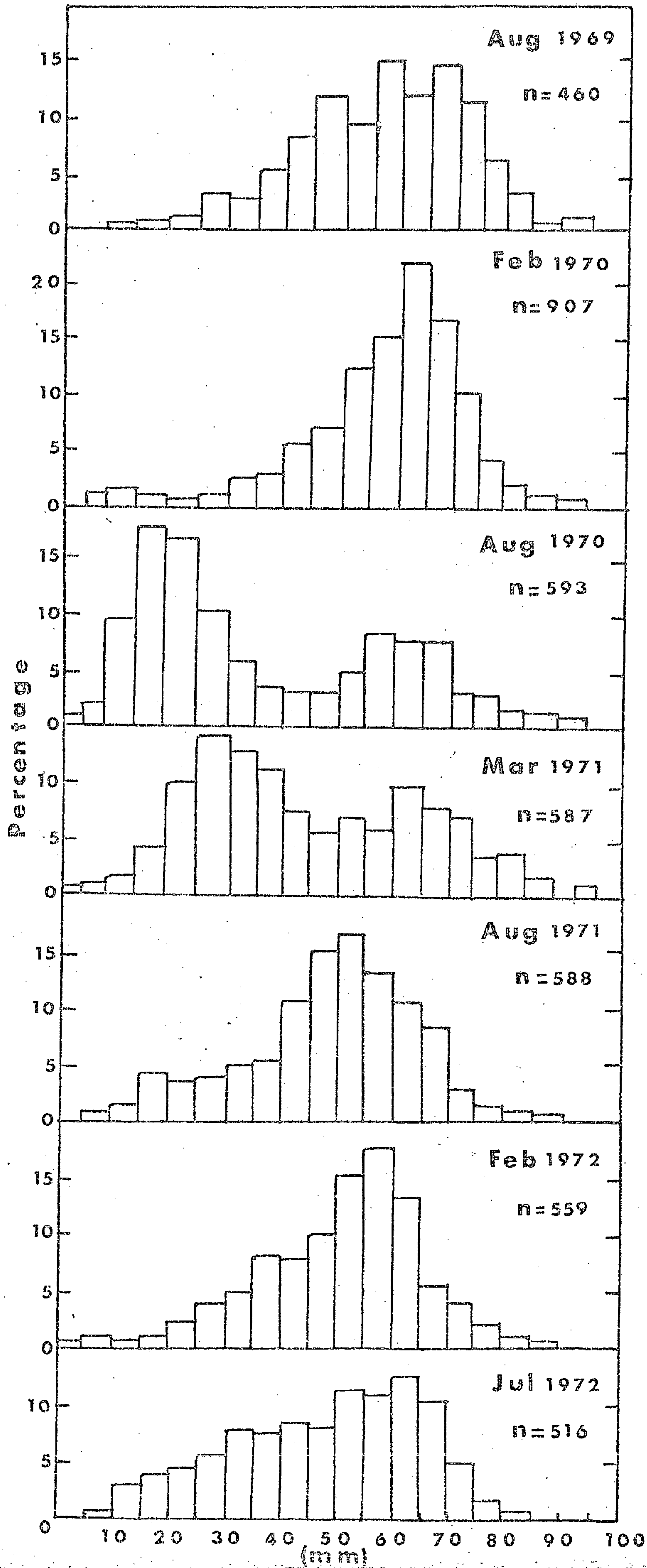
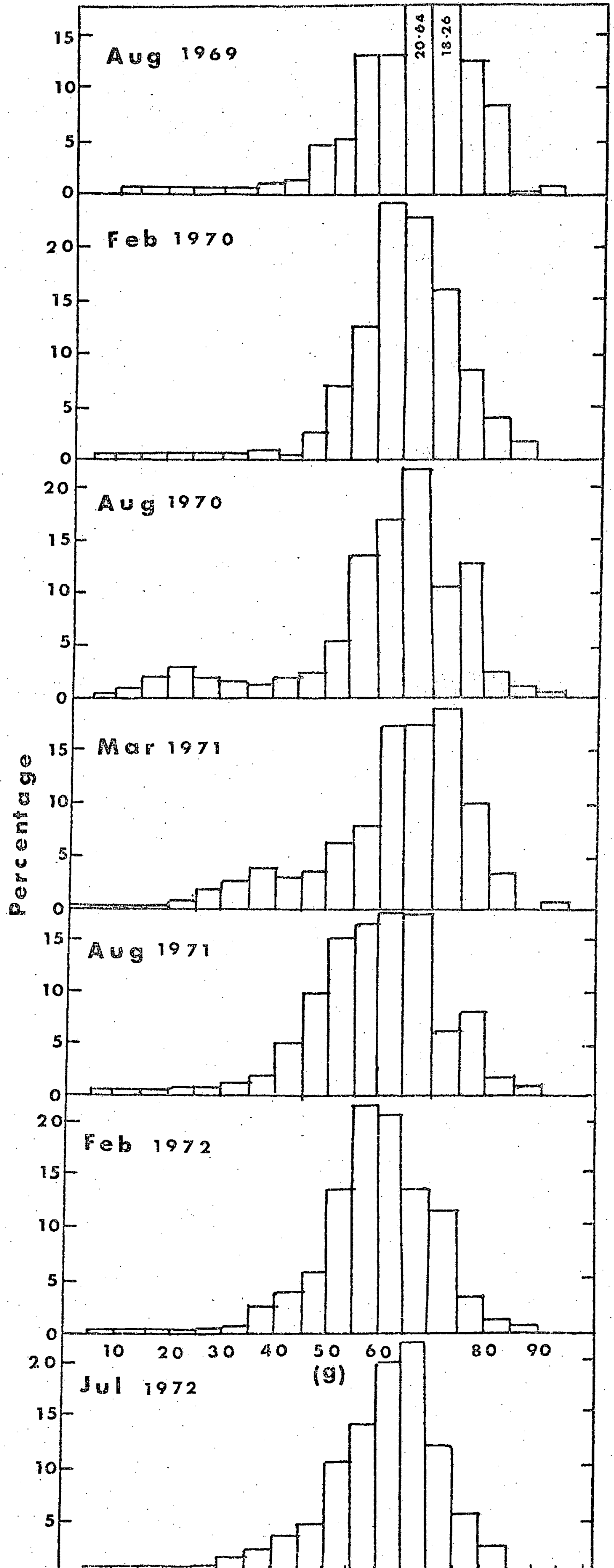


FIGURE 11

CHANGES IN THE PERCENTAGE WEIGHT FREQUENCY DISTRIBUTION OF THE CLARINBRIDGE OYSTER POPULATION BETWEEN AUGUST 1969 AND JULY 1972.



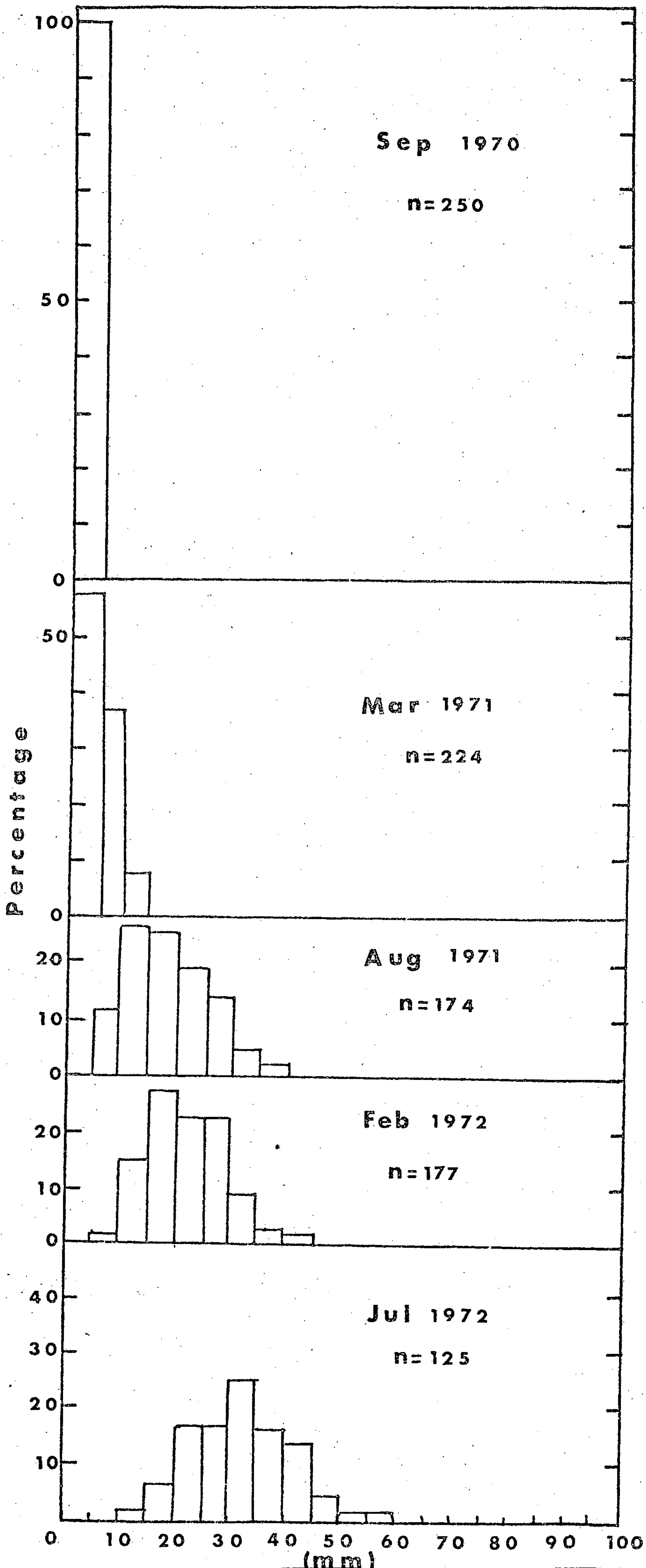


FIGURE 12

CHANGES IN THE PERCENTAGE SIZE FREQUENCY DISTRIBUTION OF CLARINBRIDGE OYSTER SPAT BETWEEN SEPTEMBER 1970 AND JULY 1972.

as is shown by the emergence of groups of 'small-brood' oysters in August 1970 and August 1971. This gap in the data was filled by monitoring the growth of spat which had been collected on tiles in August 1970. Figure 12 presents the changes in structure of that particular size-class (which was under-represented in the main survey) between August 1970 and July 1972.

Discussion

In August 1969 the bulk of the population, in terms of numbers, occupied the 40 to 75mm size range. By February 1970 a distinct modal size class (61 to 65mm) had developed and the faster-growing spat of summer 1969 along with the slower-growing spat of what must have been a poor spatfall in 1968 began to appear. In August 1970 the 1969 brood showed up strongly with modal classes covering the 16 to 25mm size range, whilst the larger modal size classes showed no increase in size, but a diminution in proportions. By March 1971 the 1969 brood had increased its modal range to 26 to 40mm but had declined in numbers relative to the larger size class which had, as a whole, increased by 5mm. Figure 12 shows that the 0 to 15mm group in Figure 10 was probably the first signs of the 1970 spatfall in the adult stocks.

By August 1971, the 1969 brood had caught up and merged with the older size classes to produce a single (approximately normal) dominant class with a mode of 51 to 55mm. The 1970 settlement, which had a modal size of 16 to 20mm appears to have merged in with the slow growers of the previous year's brood. Since all the 1970 spat exceeded 5mm in diameter by February 1971, the smallest size class in February 1972 must have been 1971 spat. The July 1972 histograms in both Figures 10 and 12 show that growth had occurred in the smaller size classes (as is confirmed by results presented later). The absence of the 0 - 5mm size class in Figure 10 confirms that the 1971 spatfall was poor, as was suggested by the spat settlement studies described in Chapter IV.

The bulk of the biomass of the population was maintained in the size range 50 to 70mm throughout the study period. Only the 1969 spatfall created any modal peak in the smaller size classes - between August 1970 and March 1971, after which it merged with the main group.

The effect of fishing on the stocks is not clearly shown in the percentage size frequency histograms. This is not surprising since the exploitable size classes (over 76mm) represented only 1.6% to 6.4% of the total population. However, there are discernible decreases in the proportions of commercial size oysters in the percentage weight frequency histograms between the mid-summer measurements (July and August) and the post fishing-season measurements (February and March).

It is impossible to age oysters by means of growth rings such as occur in scallops (<u>Pecten maximus</u>) and a variety of other bivavle molluscs. It is also difficult to distinguish age classes in size frequency histograms because the great variation in growth rates within and between age classes causes them to merge and lose their separate identities - as was the case with the 1969 age class (Figure 10). However, Sheldon (1967) showed that by plotting the percentage weight frequency distribution of the right (flat) valve a number of modes, coinciding with various age-classes, appeared. These modes compared reasonably well with those of oysters of known age. Therefore, in August 1971, 200 right valves were cleaned, allowed to come to equilibrium with atmospheric humidity (Sheldon, 1967) and weighed. Figure 13 presents the weight frequency distribution of the shells. Strong modes are not apparent, and only by estimating length from the length-weight regression line and by taking the known mean size of 2 year old (1970) oysters can the age classes be presented on the histogram be deduced. These results tie in well with the growth data presented later which suggests that Clarinbridge oysters take 6 to 7 years to reach moderate market quality (exceeding 76mm and 60g).

A further attempt to determine the age distribution of Clarinbridge oysters by polymodal analysis using probability paper (Harding, 1949; Cassie, 1954) was unsuccessful.

4. Length-Weight Relationship

The length-weight relationship of Clarinbridge oysters was determined on two occasions. In May 1970, 375 oysters were dredged directly from the seabed (randomly selected) and each was cleaned, weighed to the nearest 0.1g and measured across its widest diameter to the nearest millimetre. In June 1971 the procedure was repeated with 400 randomly selected oysters. Correlation coefficients were determined and regressions

FIGURE 13. THE PERCENTAGE WEIGHT FREQUENCY DISTRIBUTION OF RIGHT VALVES OF 200 CLARINBRIDGE OYSTERS.

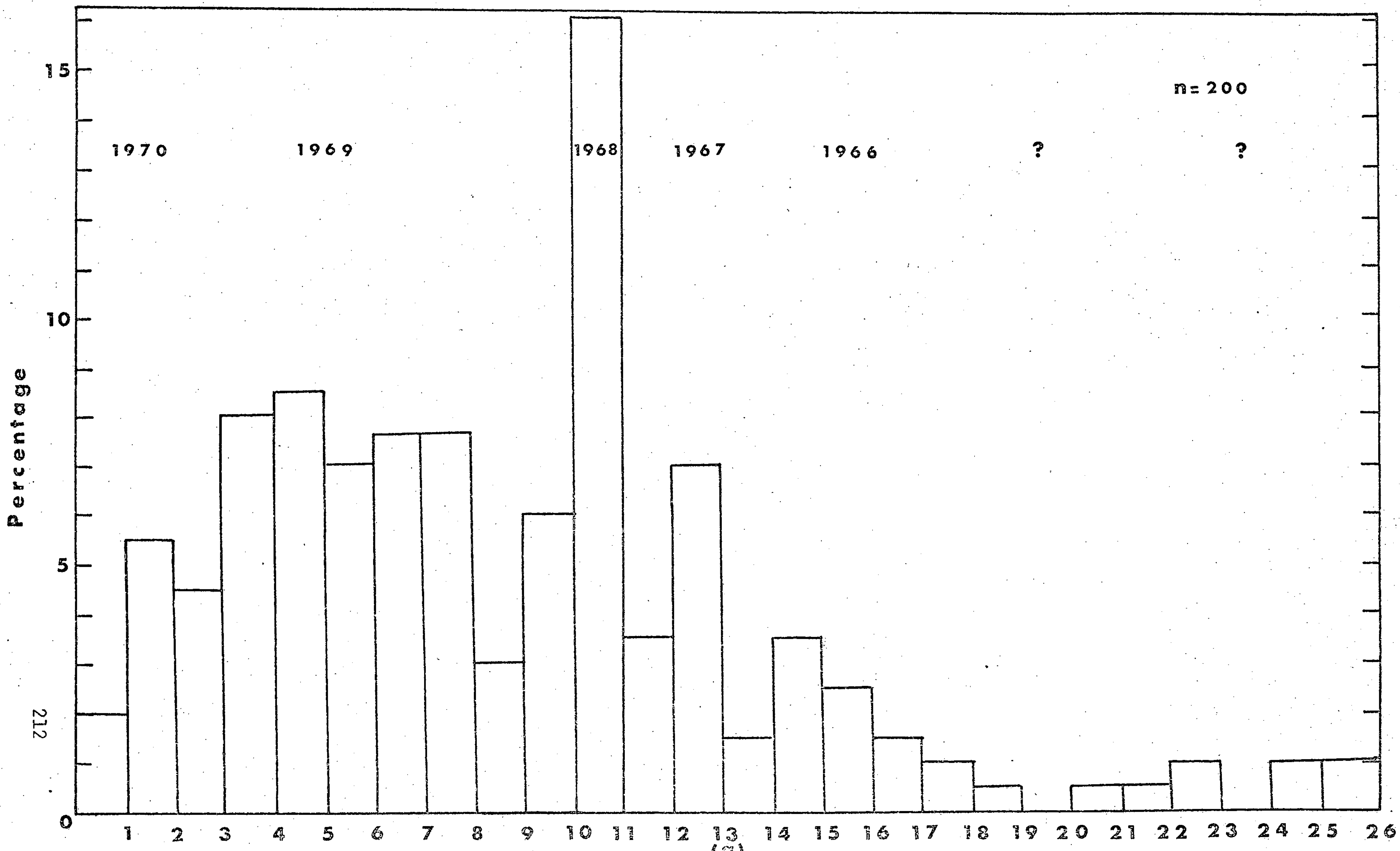


FIGURE 14

THE LENGTH-WEIGHT RELATIONSHIP OF CLARINBRIDGE OYSTERS (1-100g).

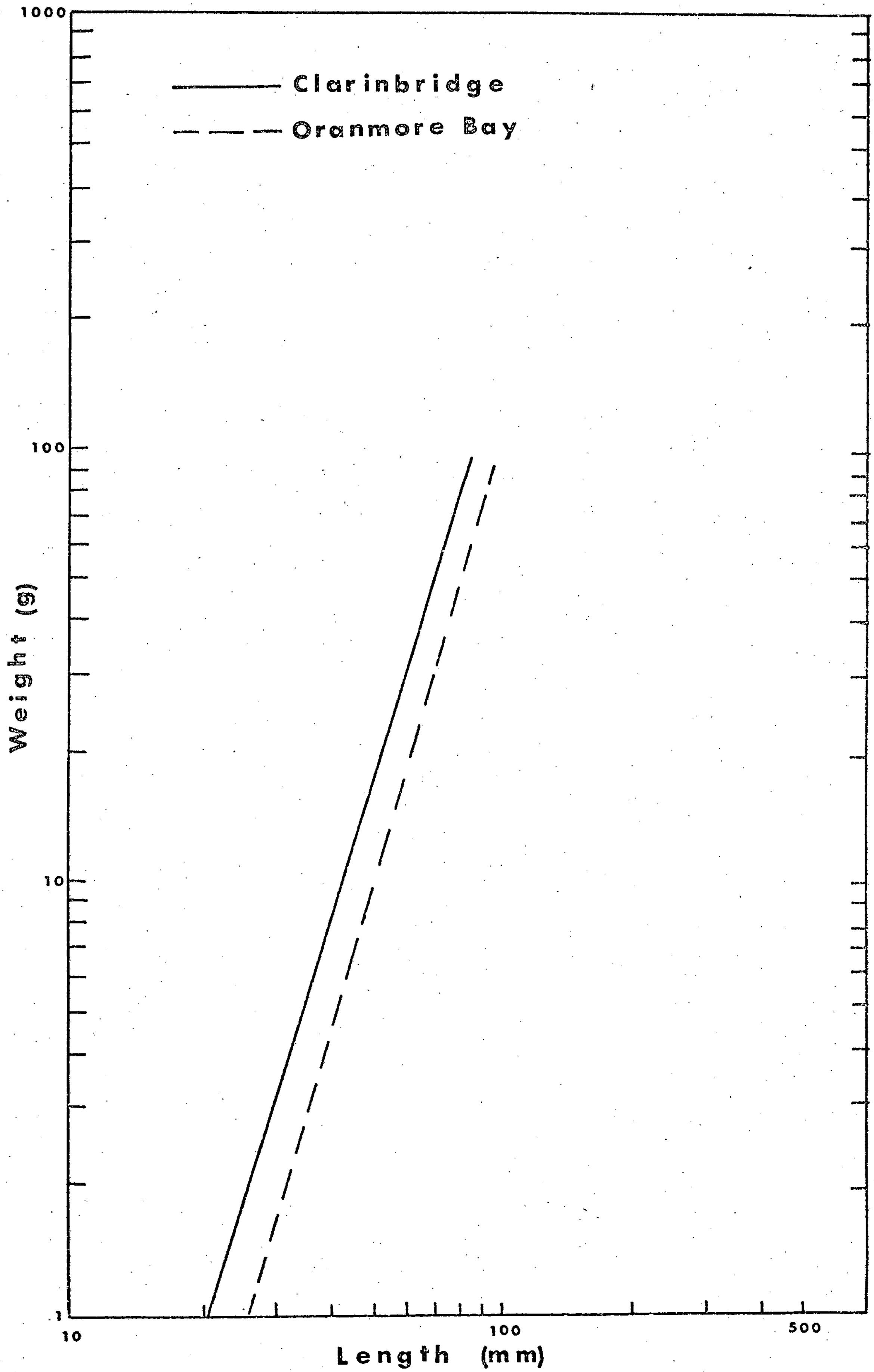
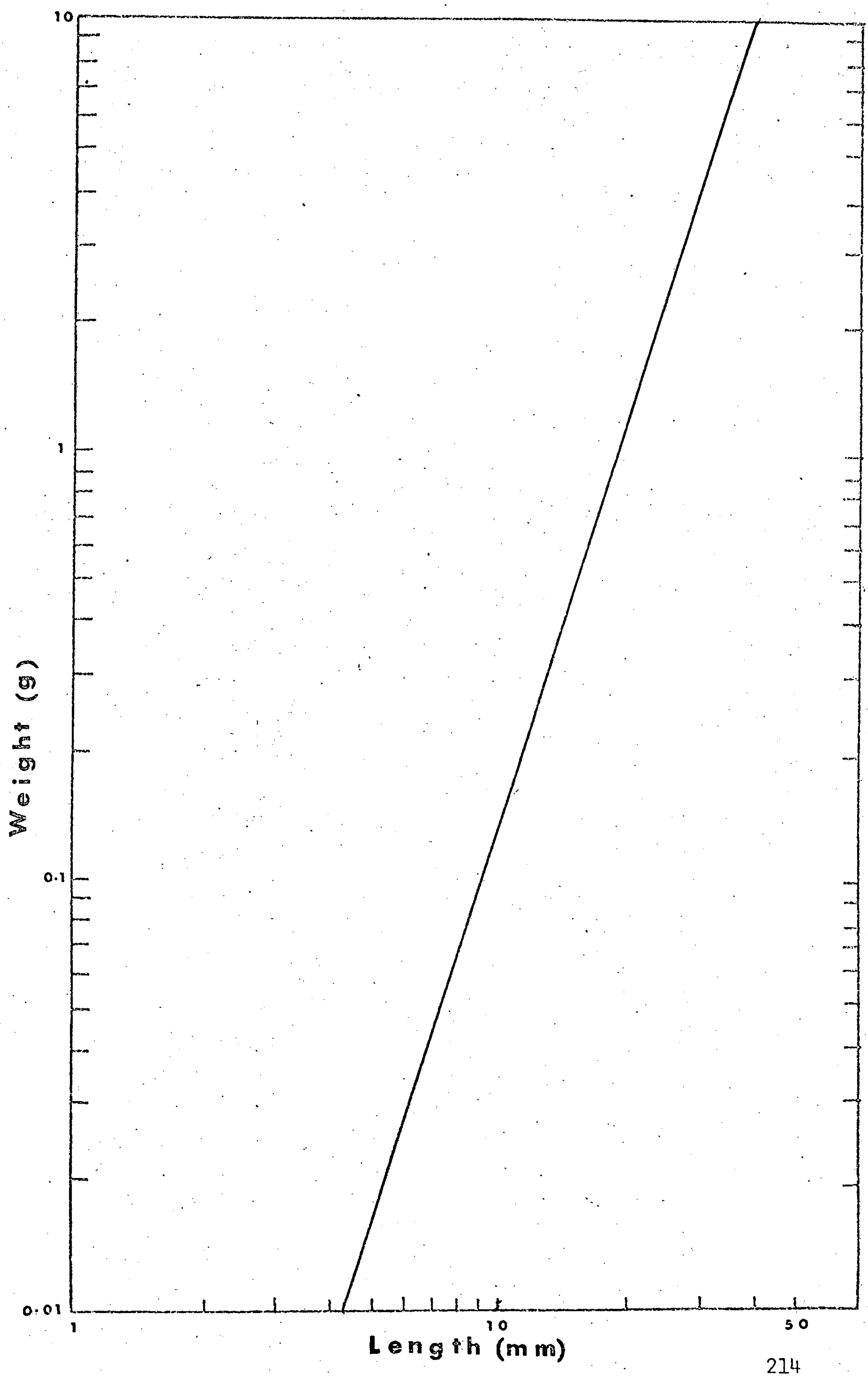


FIGURE 15

THE LENGTH-WEIGHT RELATIONSHIP OF CLARINBRIDGE OYSTERS (0.01-10g).



calculated using the method of least squares. The values obtained were substituted in the equation:

$$\text{Log } W = \log a + b \log L$$ where

W = weight

L = length

a = intercept of the regression line on the Y axis

b = regression coefficient = slope of the regression line.

The results are summarised in Table 43 below and the regression line for the 1971 sample is plotted in Figure 14.

TABLE 43

LENGTH-WEIGHT RELATIONSHIP OF CLARINBRIDGE OYSTERS

	1970	1971
Number examined	375	400
Size Range	33m x 5.0g - 87mm x 105g	21mm x 1.4g - 83mm x 91.7g
Correlation Coefficient	0.9295	0.9733
a	log 0.0047	log 0.0001
b	2.9191	3.0768

1970 Log W = log 0.0047 + 2.9191 log L

1971 Log W = log 0.0001 + 3.0768 log L

There was a significant difference between b (1970) and b (1971) at the 95% level, but no significant difference between either value of b and 3, indicating that growth, in the specimens examined, was isometric.

Unexpectedly there was a high degree of correlation between the maximum diameter and total weight, in spite of the irregular shape of many of the oysters examined. Thus, although Walne (1958) says that it is impossible to estimate reliably an oyster's weight when only its mean diameter (Walne used the mean of the anter-posterior and dorsi-ventral measurements) has been recorded, because of the irregularities of its shape, it is felt that a well fitted regression line (standard error of W about the regression line (1971) = 0.009) can provide useful background information, if the latter is used cautiously. While it may not be possible to estimate the weight of an individual oyster accurately from the regression line it can provide basic information for general production studies and also provide a basis for a comparison of the growth characteristics of various populations. For example in Figure 14 the calculated regression for Clarinbridge oysters (1971 sample) is plotted with the regression line (fitted by eye) for the faster growing oysters of the nearby Oranmore Public Oyster Fishery.

In Figure 15 the 1971 regression line has been extrapolated back to W = 0.01g in order to give an impression of the dimensions of hatchery-reared oysters which will have to be handled by oyster farmers in the future. (See Chapter VII.)

5. Growth

(a) Methods

(i) Spat

The oyster spat used in this study were obtained by exposing limed tiles during the period of spatfall in August 1970. Four tiles, holding a total of approximately 250 spat on both sides, were placed in plastic mesh bags and located on the seabed at the centre of the oyster bed. A control set of four tiles, also holding approximately 250 spat, was placed in a tray at L.W.S.T. level to the north of the experimental tiles (Shore laying - Map 8).

All live spat remaining on the tiles were measured to the nearest 0.5mm at monthly intervals from October 1970 to October 1971, after which they were measured to the nearest millimetre. Monthly measurements were continued until August 1972 when the spat were two years old.

(ii) <u>Adults</u>

Preliminary growth studies were initiated in March 1970. Two sets of oysters, each comprising four size classes (41-45mm; 51-55mm; 61-65mm; 71-75mm) containing 100 oysters each were employed. One set was placed in each of four trays (3ft x 2ft and 3 ins. above the seabed) at the L.W.S.T. level and the other was placed on the seabed in four separate enclosures nearby and at the same tidal level. Each group of oysters was weighed at monthly intervals until December 1970.

The results of this experiment showed that (a) there was no substantial advantage in holding the oysters in trays and (b) that it would be necessary to observe the growth of intermediate size classes in order to obtain a composite growth curve, representative of the whole population.

Accordingly, in March 1971, twelve size classes were selected as indicated in Table 44. Two hundred individuals were collected for the size classes 31-35mm, 41-45mm, 51-55mm, 61-65mm and 71-75mm. One hundred oysters from each of these classes were weighed and measured and placed on enclosed layings at extreme L.W.S.T. level and left as undistrubed controls until January 1972.

The remaining oysters were divided into sub-groups of 25 (to provide comparative data for statistical analysis if large differences in growth rates appeared within the various size classes) and after each individual had been weighed (to the nearest 0.1g) and measured (to the nearest millimetre) they were placed in weighted plastic mesh bags and laid on the seabed at the centre of the oyster bed. Three further size classes (21-30mm, 26-30mm and 76mm +) were treated in the same manner but there were too few oysters in these classes to provide controls. All these bagged oysters were weighed and measured at monthly intervals until the end of May 1972.

One hundred individuals of each of the intermediate size classes (36-40mm, 46-50mm, 56-60mm and 66-70mm) were weighed and placed in larger mesh bags and weighed as complete groups at monthly intervals. This was done to provide intermediate data between the main groups if these did not grow sufficiently fast to be recruited into the next main size class during the study period.

(b) Results

(i) Spat

Figure 16 presents the mean growth of Clarinbridge oyster spat from August 1970 (settlement) to August 1972.

FIGURE 16. THE MEAN LENGTH INCREMENT OF CLARINBRIDGE OYSTER SPAT BETWEEN AUGUST 1970 AND AUGUST 1972

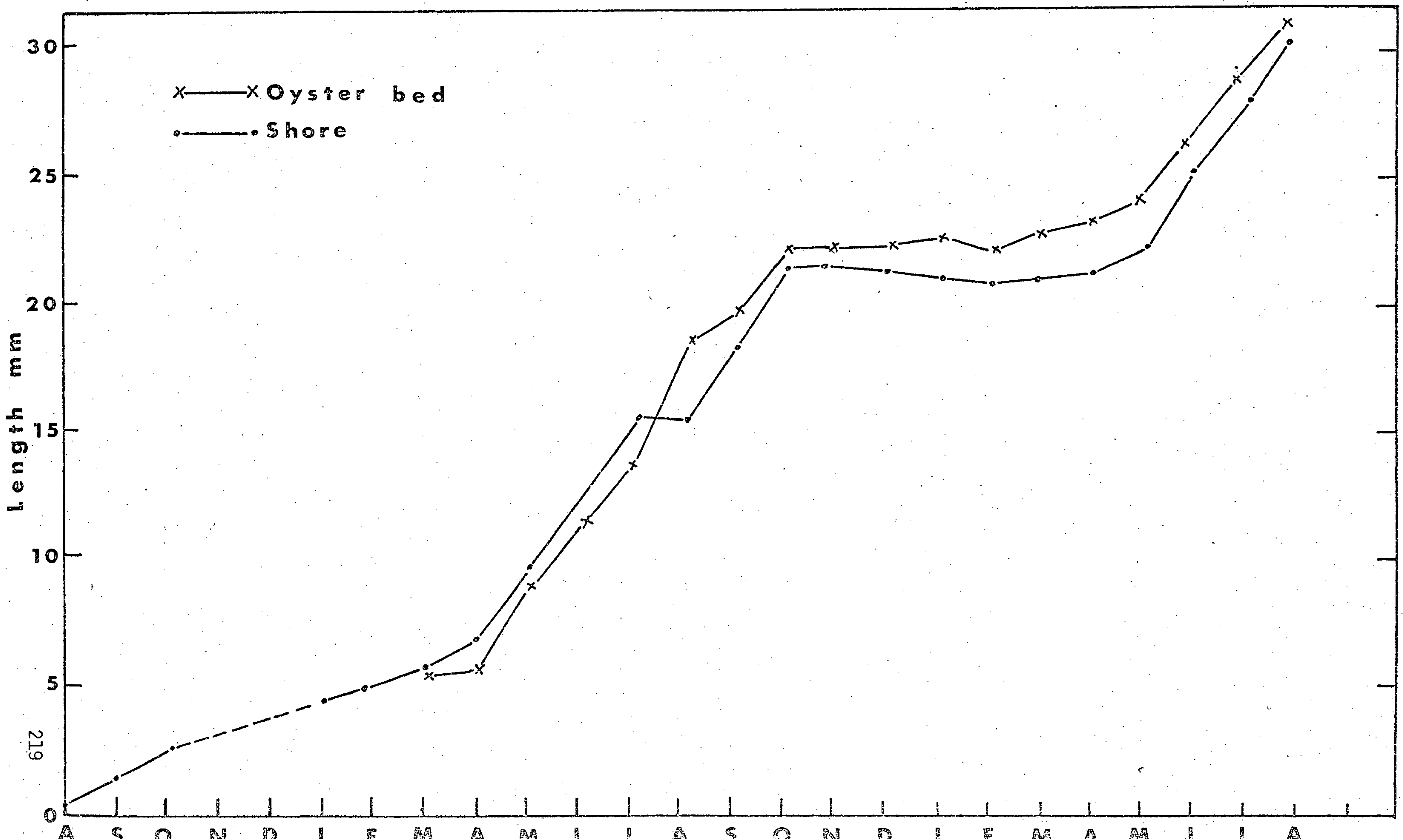


Figure 22 illustrates the relative growth of the spat.

There was no significant difference (at the 95% level) between the final mean sizes of the spat held at L.W.S.T. level and those located at the centre of the oyster bed.

(ii) Adults

Table 44 below summarises the initial composition of the 1971-1972 growth experiments. Figure 17 illustrates the weight increments of the 1970 growth groups.

TABLE 44

THE INITIAL COMPOSITION OF OYSTERS USED IN THE 1971-72 GROWTH EXPERIMENTS

Size class (mm)	Numbers per group	Status
21-30	2 x 25	1
26-30	2 x 25	1
31-35	4 x 25	1
31-35	100	C
36-40	100	2
41-45	4 x 25	1
41-45	100	C
46-50	100	2
51-55	4 x 25	1
51-55	100	C
56-60	100	2
61-65	4 x 25	1
61-65	100	C
66-70	100	2
71-75	4 x 25	1
71-75	100	C
76+	4 x 25	1

1 = main group; 2 = intermediate group; C = shore control

FIGURE 17

THE MEAN WEIGHT INCREMENTS OF SELECTED SIZE GROUPS OF CLARINBRIDGE OYSTERS DURING 1970.

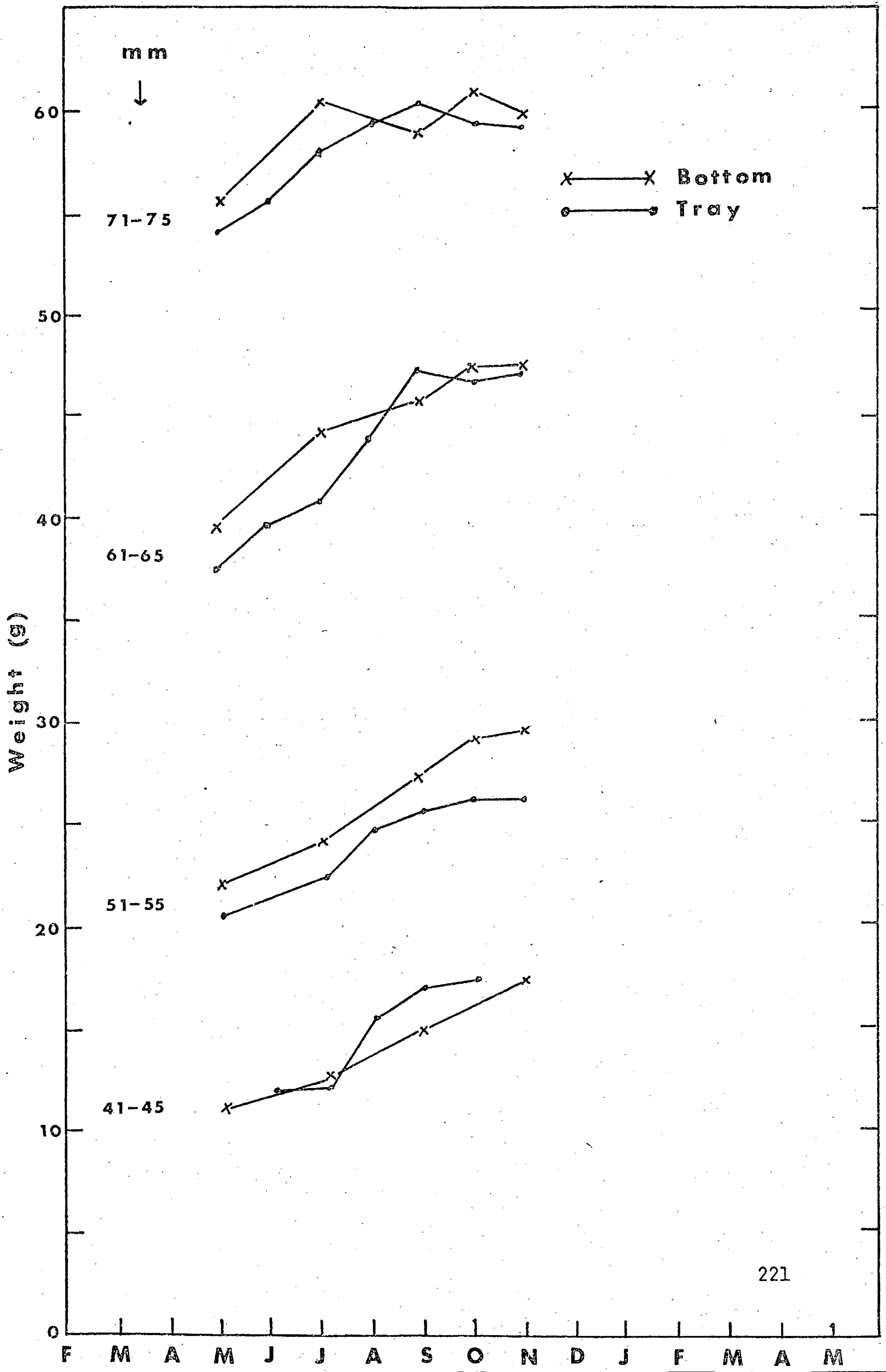


Figure 18 presents the length increment of various size classes between March 1971 and May 1972. Figure 19 presents the growth of these groups in terms of weight.

The control groups laid on the shore were disturbed by gales and several groups became mixed. However, it was possible to salvage the majority of the oysters and place them in their correct size classes. The mean weights of the control groups in March 1971 and January 1972 are shown on Figure 19 and presented in Table 45 below where they are compared with the experimental groups.

TABLE 45

COMPARISON OF THE WEIGHT INCREMENT OF EXPERIMENTAL AND CONTROL OYSTERS AT CLARINBRIDGE IN 1971-72

Size Group	Original mean wt(g) (n=100)		Final mean wt(g) (n)		Mean wt. increment (g)	
	Bags	Shore	Bags	Shore	Bags	Shore
31-35	4.46	4.48	13.93 (69)	11.35 (74)	9.47	6.87
41-45	8.24	9.11	18.93 (73)	19.41 (71)	10.69	10.30
51-55	18.23	23.24	27.24 (83)	28.23 (86)	9.01	4.99
61-65	36.24	40.62	44.02 (79)	43.26 (72)	7.78	2.64
71-75	61.49	59.51	64.98 (79)	60.15 (66)	3.49	0.64

(c) Discussion

(i) Spat

At settlement in 1970 Clarinbridge spat were

FIGURE 18

THE MEAN LENGTH INCREMENT OF SELECTED SIZE GROUPS OF CLARINBRIDGE OYSTERS DURING 1971-72.

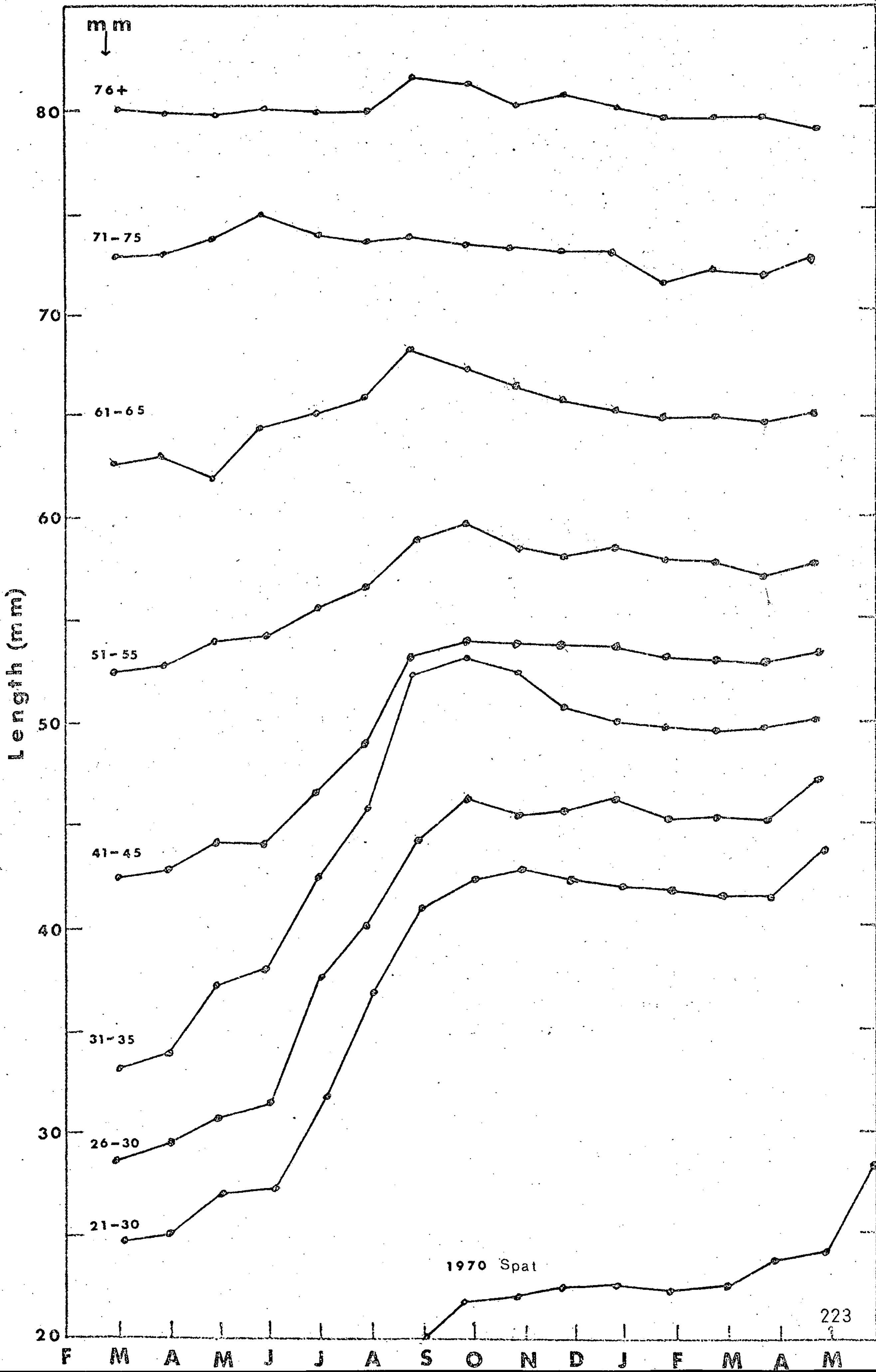
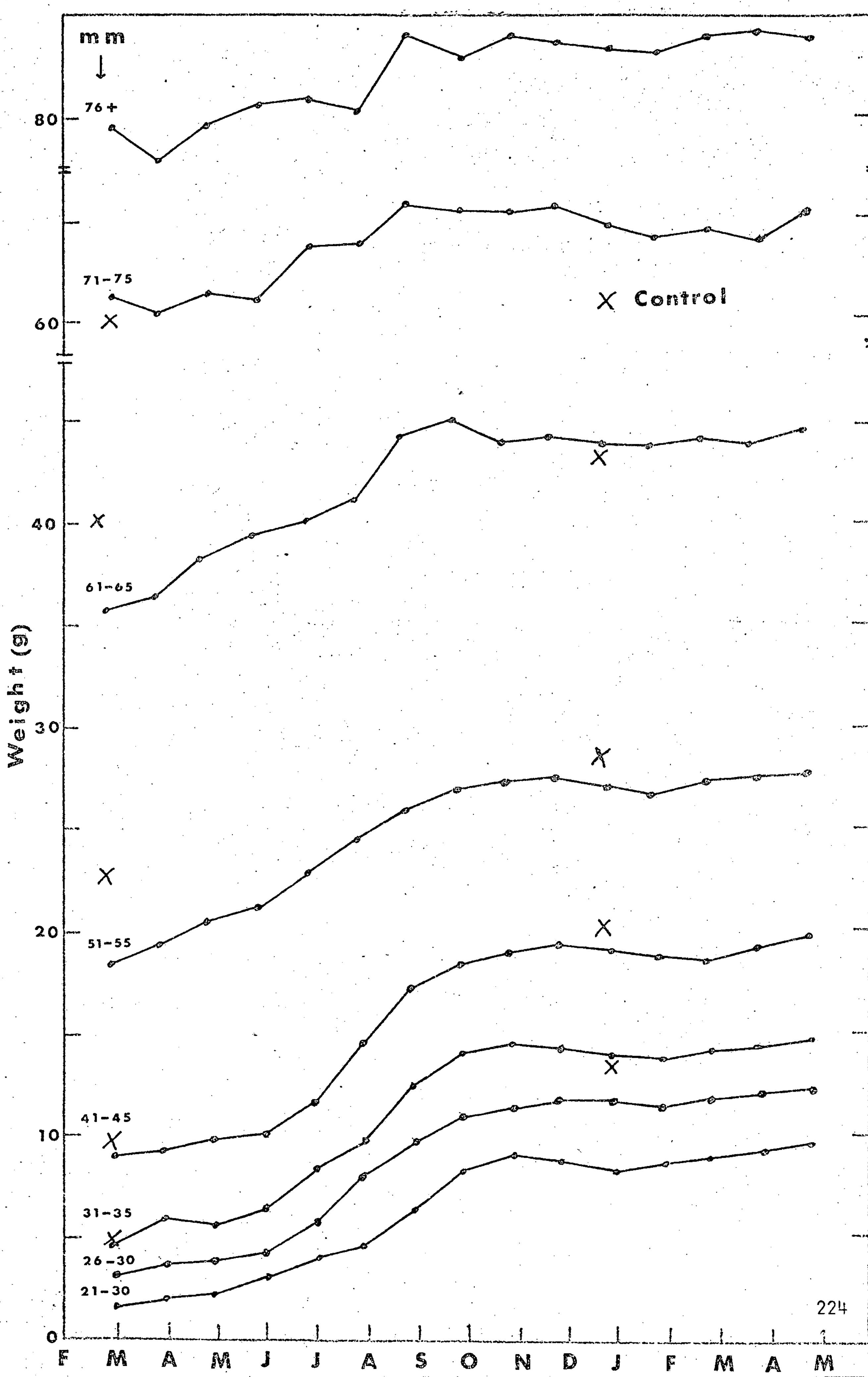


FIGURE 19

THE MEAN WEIGHT INCREMENT OF SELECTED SIZE GROUPS OF CLARINBRIDGE OYSTERS DURING 1971-72.



approximately 0.3mm in diameter. By mid-October they had attained a mean size of 2.3mm. Apparently growth continued until the end of January, but nearly ceased during February - the coldest month of the year. Rapid growth started in early May 1970 and continued until the end of October when any mean size increase became virtually undetectable. In fact the control group decreased in mean size between early November and the end of February, possibly as a result of wave action and increased exposure during the periods of low spring tides.

Slow growth resumed in early March 1971, but the onset of rapid growth did not occur until early June, a month later than in 1970.

Although there was no statistical difference ($p=0.05$) between the final mean sizes of the two groups of spat the drop in growth rate of the control group in August 1971 appears to have left this group at a slight disadvantage which was further increased by the action of waves and exposure in the winter of 1971-1972.

In the spring of 1972 it was felt that the relatively slow increase in mean size may have been due to the recruitment of 1971 spat onto the tiles, which were exposed throughout the summer of 1971. However, polymodal analysis using probability paper (Cassie, 1954) showed that only one size class was present on the tiles and that any apparent depression of the growth rate was due to other factors.

As was pointed out in an earlier section and has been noted by Walne (1958) and numerous other workers the growth rate of oysters within any particular age class is highly variable and the fast growers of a younger size class can soon merge with the slow growers of the next age class. Table 46 below illustrates this point. If the two size classes occurring in the same year (i.e., assuming growth rates similar to those observed) then it is obvious that a large proportion of each class would be indistinguishable as separate age classes. Even the mean sizes in each class are included in the range of both groups. Thus, if such merging occurs within the first two years there is little possibility of distinguishing older age classes unless they are prominent in terms of numbers.

TABLE 46

SIZE RANGE OF SPAT AT SELECTED TIMES
DURING THE STUDY PERIOD

	August 1970	August 1971	August 1972
Minimum diameter	0.25	6.5	13.0
Mean diameter	0.30	18.7	31.9
Maximum diameter	0.35	40.0	57.0

(ii) Adults

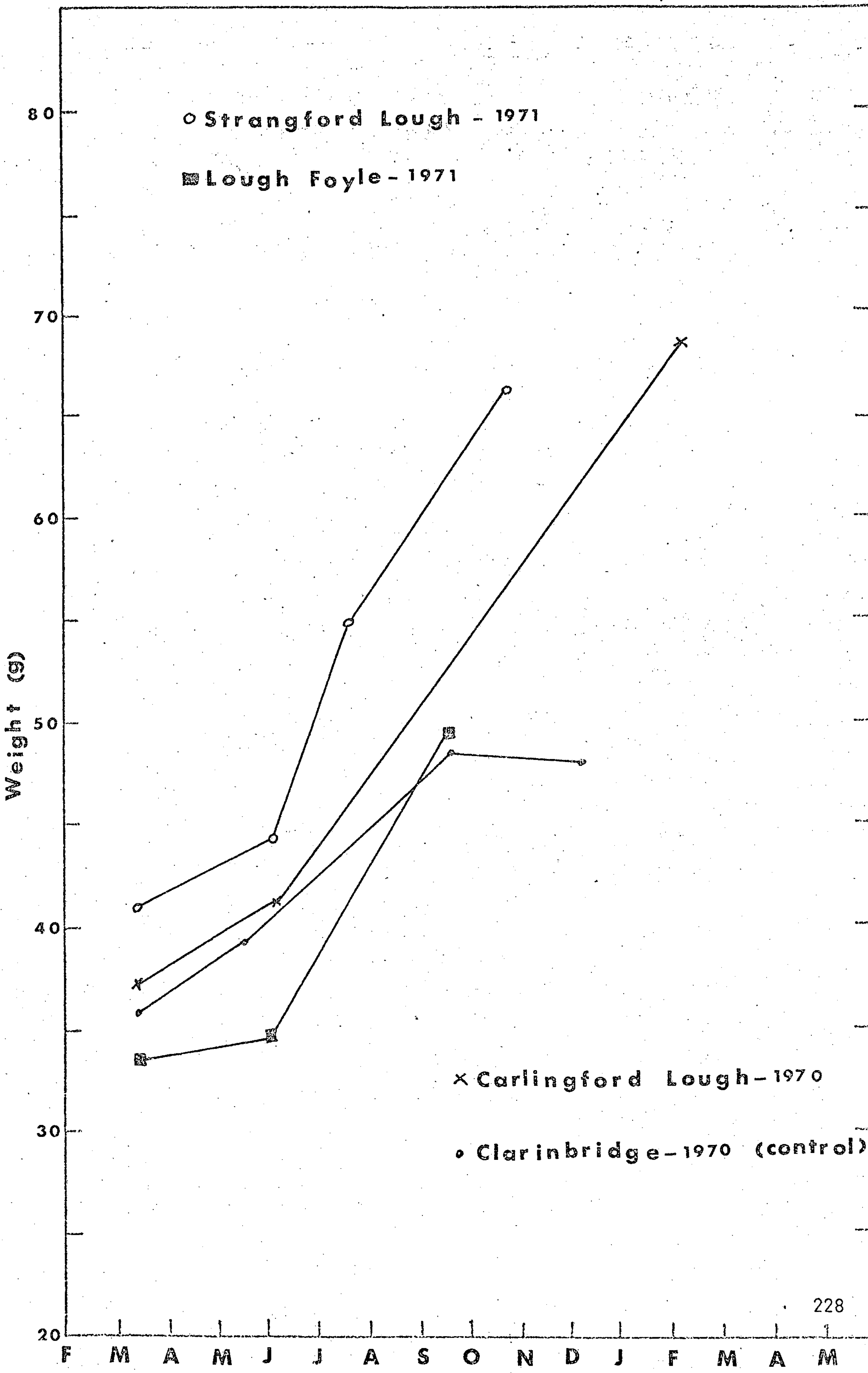
The preliminary growth trials carried out in 1970 indicated that there was no substantial difference between the growth or mortality rates of oysters held in trays and those held on the ground. The trials also showed that Clarinbridge oysters are slow growing. A comparative study of the growth of Clarinbridge oysters laid at Clarinbridge (control) and others relaid at Carlingford Lough (Whilde, 1971b) on the east coast of Ireland during 1970 confirmed that this was the case. Data on the growth of *Ostrea edulis* in Northern Ireland waters (Parsons, pers. comm.) further substantiated these findings. Figure 20 presents these differences graphically.

The more detailed information provided by the 1971-1972 trials indicated that growth is generally negligible between the end of November and the end of April and that some oysters in the larger size classes may even decrease in size and weight during this period. This is in keeping with the observations of Walne (1958) who also found that a small proportion of his experimental oysters put on shell growth between mid-February and mid-April, although the mean diameter of the whole sample did not increase until May. At Clarinbridge most growth occurred between May and the end of October and during this period a large majority of the experimental oysters increased in size and/or weight. The period of most rapid growth at Clarinbridge was from mid-June to the end of September, as it was also in North Wales (Walne, 1958).

The breeding season (June, July, August and September) had no apparent effect on the growth rate of the experimental oysters at Clarinbridge and this is in keeping with the observations of Korringa (1952) who pointed out that oysters are able to continue growing at a normal rate during the spawning period, providing the feeding conditions are satisfactory. However, Havinga (1928) found that one oyster which he weighed in water daily showed retarded growth during its breeding period and stopped growing for four days. However, since breeding activity does not occur simultaneously in a whole population it is likely that any transitory decrease in growth rate of a

FIGURE 20

THE MEAN WEIGHT INCREMENTS OF *OSTREA EDULIS* IN VARIOUS PARTS OF IRELAND



few individuals will be masked by the continuing normal growth of the remainder of the population.

It was particularly noticeable that the larger size classes (71-75mm and 76mm+) decreased slightly in mean diameter during the year, although they did put on weight during the same period. This may have been due to continual abrasion of the shell margins in the plastic bags or it may reflect feeding conditions which may only have been adequate for maintenance, body growth and shell thickening, and not for shell extension. If the former had been the case the same effect would have been expected in the smaller size groups where, in fact, it was not apparent. This suggests that some inherent factor in the larger oysters or some unknown environmental factor adversely affected growth.

The control groups generally showed slightly poorer growth, in terms of weight increment, than the seabed groups. However, since the control groups were mixed up by storms a direct comparison of growth rates is not valid except insofar as it can be said that the monthly handling of the seabed groups appears to have had little or no effect on their growth rates compared with those of the control groups.

The design of the 1971-1972 growth experiment made it possible to determine the general rate of recruitment from one size class to another. Table 47 presents the percentage numbers of the survivors of each class which were recruited into large size classes between March 1971 and March 1972.

TABLE 47

RECRUITMENT OF CLARINBRIDGE OYSTERS IN 1971-1972

Initial Size Class (mm)	Percentage of Survivors Recruited into Larger Size Classes									
	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	71-75	76+
20-30	10.5	30.0	30.0	21.0	8.5	--	--	--	--	--
31-35	--	5.3	6.7	20.0	51.3	16.7	--	--	--	--
41-45	--	--	15.0	10.0	25.0	30.0	15.0	5.0	--	--
51-55	--	--	--	--	20.5	41.0	28.5	10.0	--	--
61-65	--	--	--	--	--	--	50.0	30.0	20.0	--
71-75	--	--	--	--	--	--	--	20.0	65.0	15.0

The above figures show that all oysters in the smaller size classes moved up at least one 5mm size class during the year and the majority moved up two or three classes. The first signs of a slower growth rate occurred in the 41-45mm group in which 15% of the survivors failed to leave the initial size class. The proportion of "non-starters" increased with size and in the 71-75mm group 85% of the survivors either failed to move up or decreased in size.

If the changes in mean size of each size class are considered, the following observations can be made. The 20-30mm group reached the 31-35mm class by the end of July and the 41-45mm class by the end of July and the 51-55mm class by the end of September 1971 and remained in this class until May 1972. In contrast the faster growing 31-35mm group dropped back into the 46-50mm class where it remained until May 1972. The 51-55mm size class moved up only to the 56-60mm class and similarly the 61-65mm group moved up only to the lower end of the 66-70 class.

The largest size classes remained in their initial classes.

These general observations suggest that an 18-month old oyster measuring 25mm in diameter would reach approximately 40mm at 30 months, 52mm at 42 months, 60mm at 54 months, 68mm at 66 months ($5\frac{1}{2}$ years) and probably be recruited into the commercial stock during its 7th or 8th year.

In terms of weight the recruitment rate is similar in the smaller size classes (20-45mm) but in general there was no recruitment between the larger size classes.

Relative Growth

Relative growth - growth increments expressed as a percentage of the unit of tissue which produced them - is a useful way of expressing the growth characteristics of a particular population or species because it illustrates the degree to which smaller individuals grow faster than larger individuals. Figure 21 presents the relative growth of oysters at Clarinbridge between March 1971 and March 1972 in terms of weight increment. In addition a relative growth curve based on Walne's data (Table 1, 1958) is presented to show how much faster oysters grow at Tal-y-foel. Three individual points are also plotted to illustrate the possible position of the relative growth curves of oysters relaid in Strangford Lough and Carlingford Lough where growth is faster than at Clarinbridge

The relative growth curve of the shore control is also presented and this indicates a lower growth rate on the shore than in the bags on the oyster bed. However, since

FIGURE 21

THE RELATIVE WEIGHT INCREMENTS OF OYSTERS AT CLARINBRIDGE AND ELSEWHERE.

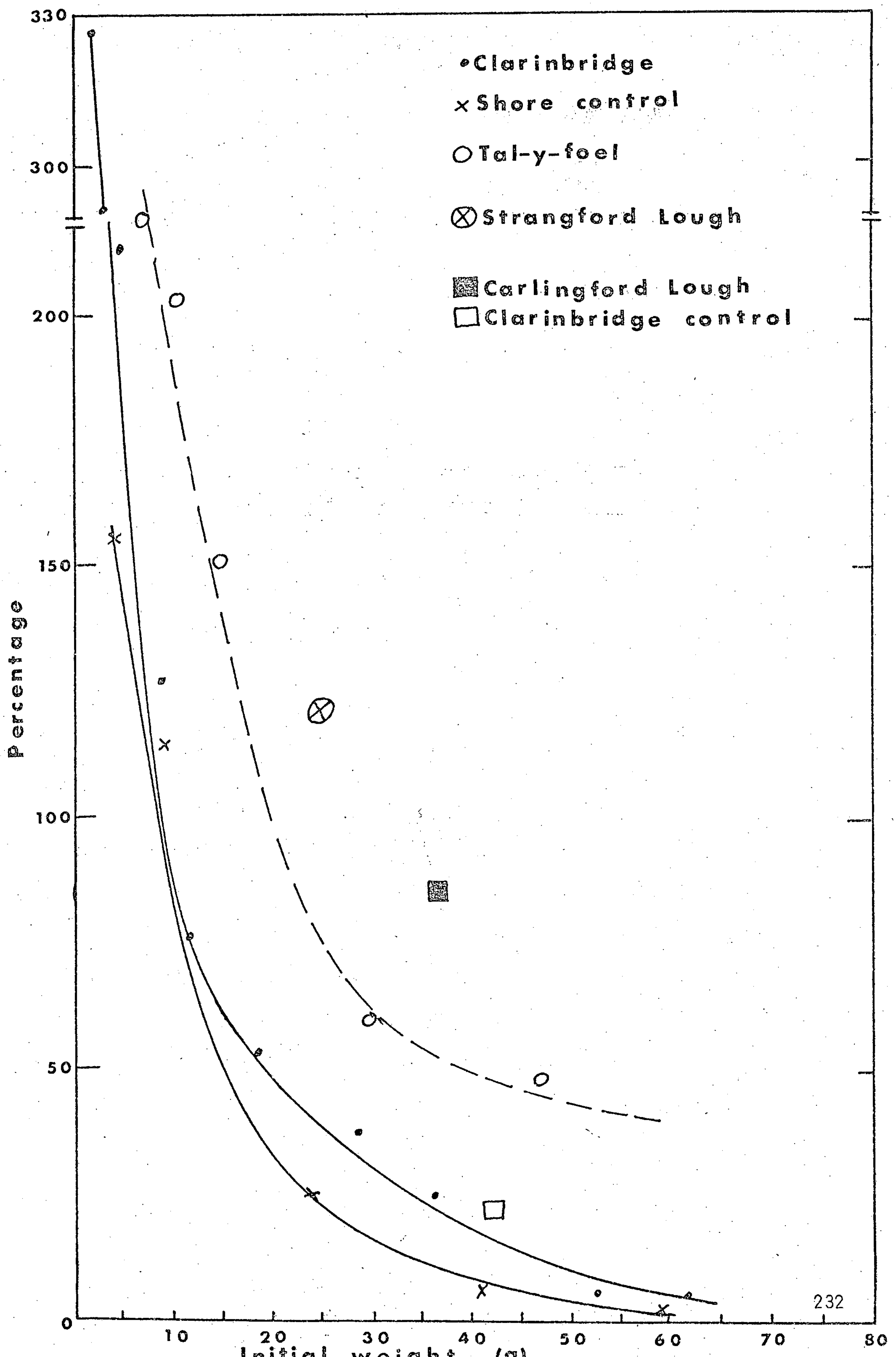
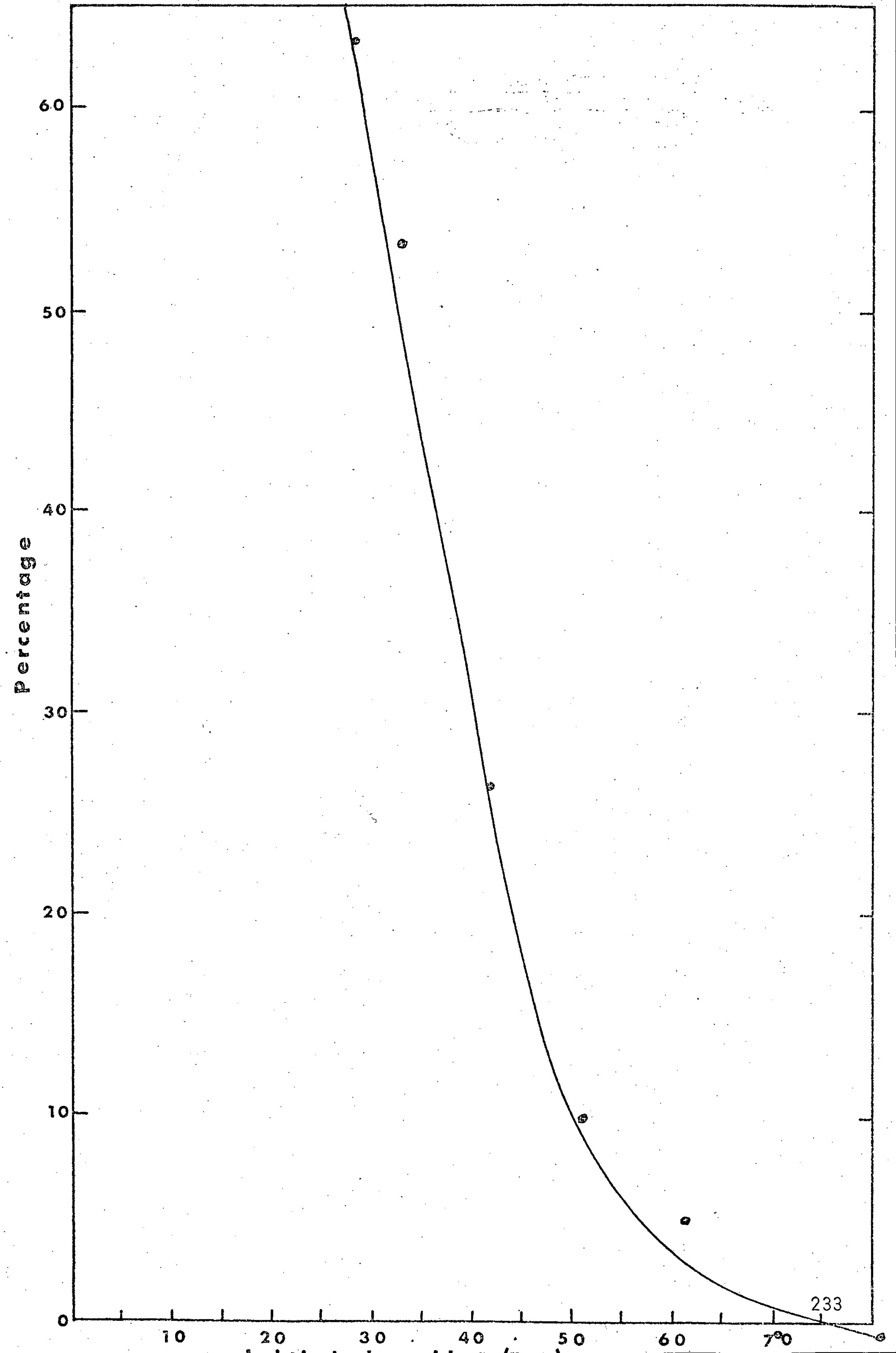


FIGURE 22

THE RELATIVE LENGTH INCREMENT OF CLARINBRIDGE OYSTERS.



the various size groups of the control population were mixed up during storms the difference may not be as relevant as it first appears.

Figure 22 shows the relative growth curve in terms of length. The relative increment in the first year (i.e., from spat to a mean size of nearly 19mm) is over 6,000%. However, in the second year it drops to just over 1/100th of the value.

Walne (1958) indicated that the growth rate decreases with size, even amongst oysters of the same age. This point is well illustrated in Table 48 below where the percentage increment of the smallest 1970 spat is contrasted with that of the largest individuals.

TABLE 48

DIFFERENTIAL GROWTH IN CLARINBRIDGE OYSTERS OF THE SAME SIZE

	Smallest (mm)	Mean (mm)	Largest (mm)
August 1971	6.5	18.7	40.0
August 1972	13.0	31.9	57.0
% Increase	100	71	42.5

Ford-Walford Plot

For species such as oysters, in which there is no reliable way of determining age, it is convenient to estimate certain growth parameters by means of the Ford-Walford plot (Ford, 1933; Walford, 1946), which gives a similar interpretation of growth in length to von Bertalanffy's (1938) growth equation (Hancock, 1965).

The Ford-Walford plot was obtained by plotting the mean length of 9 size classes in March 1971 (L_t) against the mean length of the same size classes in March 1972 (L_{t+1}). A straight line was obtained and from this the mean annual increment of an animal of any given size could be interpolated. The line is described by the equation:

$$L_{t+1} = L\infty \left(1-e^{-kt} + L_t e^{-kt}\right)$$

where L_t and L_{t+1} are as described above;

$L\infty$ = theoretical maximum size to which the animal can grow and is represented by the intercept of the Ford-Walford plot with the 45° line;

k = a constant which describes the rate at which the growth rate of the animal decreases with age;

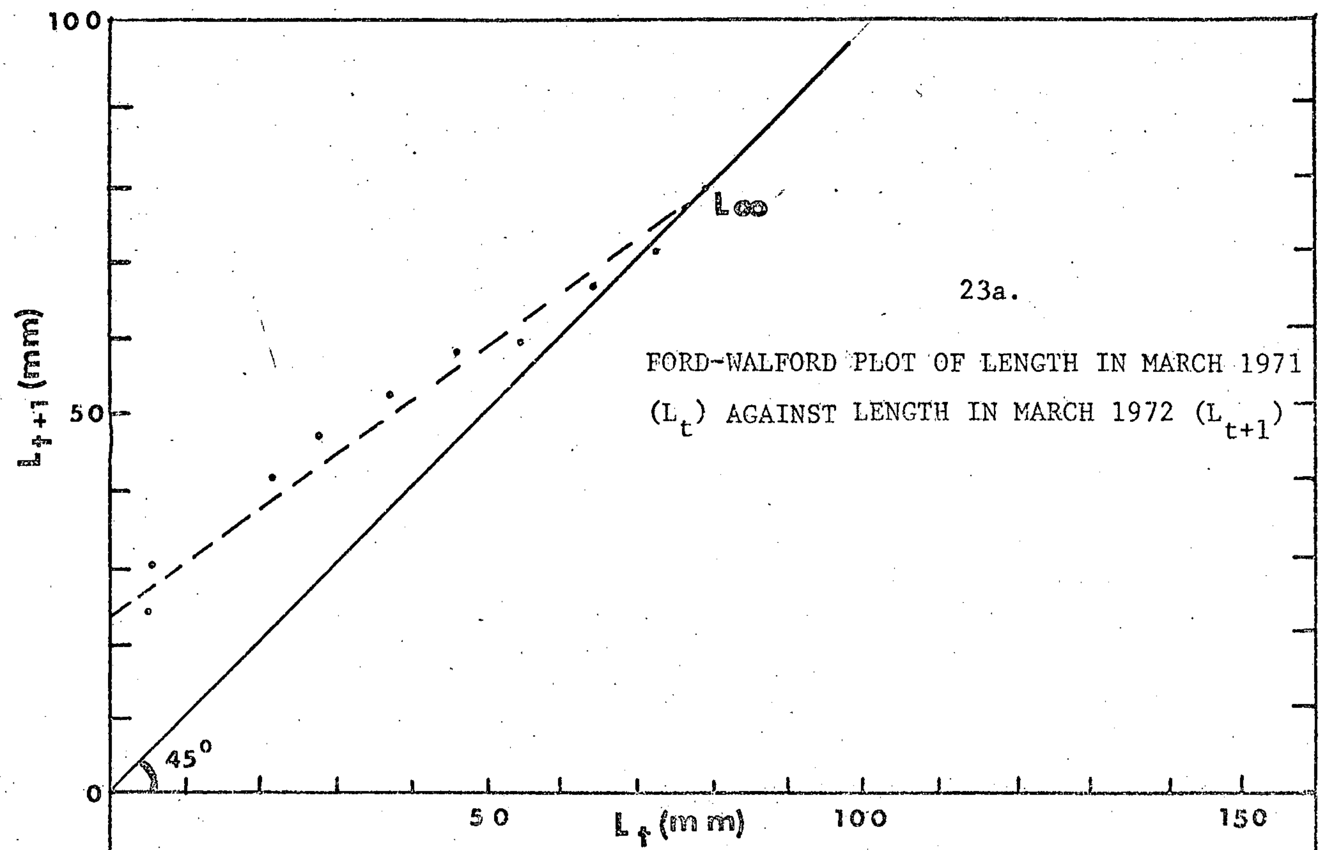
e = base of natural logarithms.

The equation was estimated as:

$$L_{t+1} = 22.988 + 0.707\ L_t$$

by regression analysis of data which was based on the increase in mean sizes between March 1971 and March 1972 of the nine size groups illustrated in Figure 18. The regression line and the 45° line are presented in Figure 23a. The theoretical

FIGURES 23a & 23b.

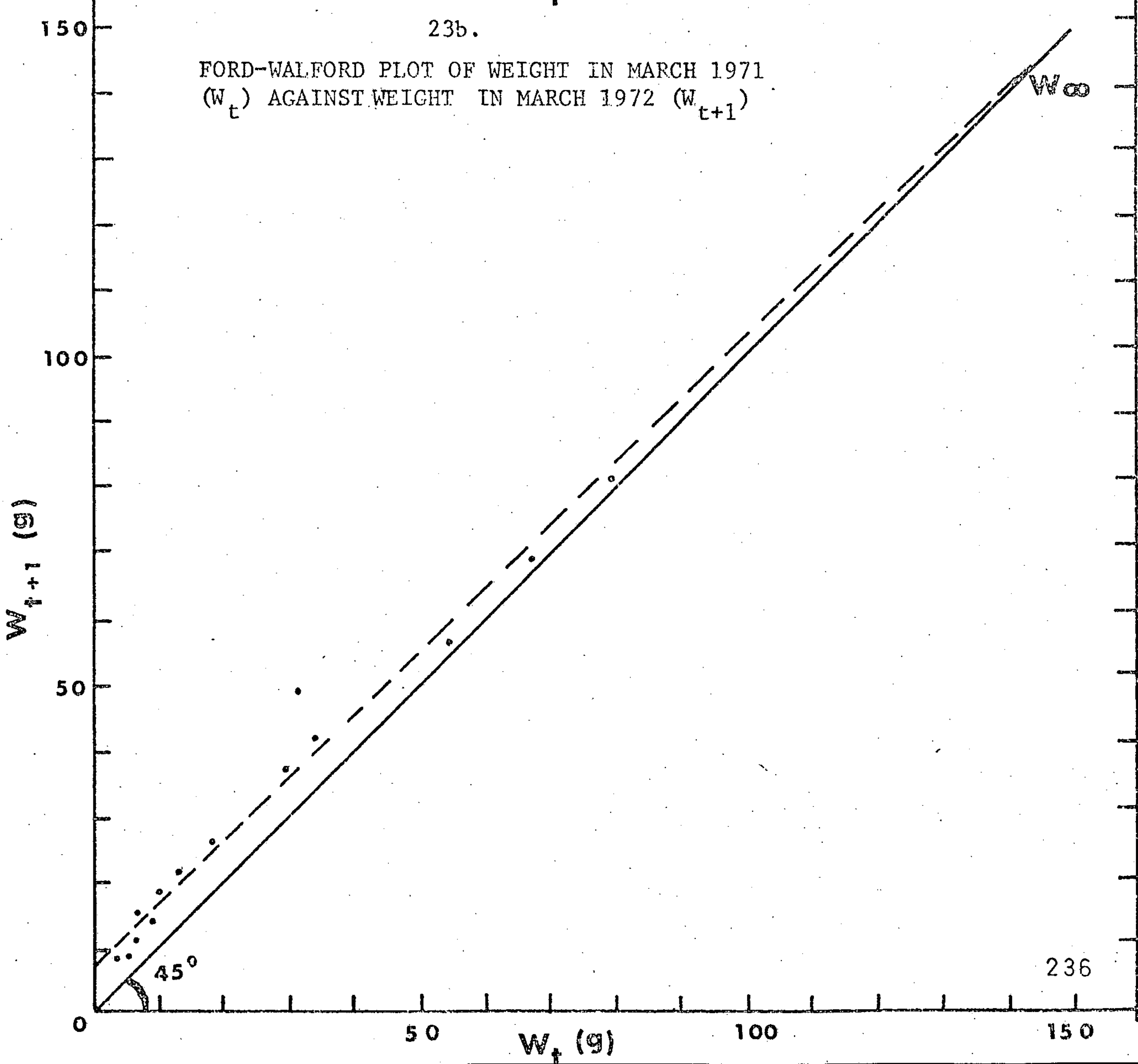


23a.

FORD-WALFORD PLOT OF LENGTH IN MARCH 1971 (L_t) AGAINST LENGTH IN MARCH 1972 (L_{t+1})

23b.

FORD-WALFORD PLOT OF WEIGHT IN MARCH 1971 (W_t) AGAINST WEIGHT IN MARCH 1972 (W_{t+1})



maximum length of 78.46 was actually lower than the maximum size recorded in the largest size group. This illustrates an important drawback in the procedure which results from the use of truncated data. As Hancock (1965) and Knight (1968) so forcefully pointed out, data relating to only part of a population may produce a plot which is biased towards the most abundant size class and thereby produce erroneous values of $L\infty$ and k because each class exhibits its own particular pattern of growth. Since it is not always known how representative a population sample is, only limited importance should be attached to the $L\infty$ value.

The erroneous $L\infty$ value calculated for Clarinbridge oysters resulted from the use of size classes (71-75mm and 76mm+) which actually decreased in size during the year. However, even when these groups were omitted from the calculation, $L\infty$ was found to be 70.25. Both these values are well below the maximum lengths recorded in the regular population surveys and considerably less than the maximum diameter recorded at Clarinbridge (142mm) which in turn is nearly 70mm less than the largest diameter of an Irish oyster observed by the author. Table 49 below indicates the occurrence of size classes larger than the calculated $L\infty$ in the monthly population surveys.

TABLE 49

PERCENTAGE FREQUENCY OCCURRENCE OF OYSTERS IN VARIOUS LARGE SIZE CLASSES

Size class (mm)	% of samples in which particular size class occurred
96-100	14
91-95	50
86-90	89
81-85	100

When weight was substituted for length the following equation was obtained:

$$W_{t+1} = 9.146 + 0.934\ W_t$$

W_∞ was calculated to be 138.58g, which, by interpolation from the length-weight regression line presented earlier, is equivalent to a length of 100mm, which is closer to the observed maximum size of Clarinbridge oysters than the calculated L_∞ value. The Ford-Walford plot (weight) is given in Figure 23b.

The true L_∞ value is further masked by the effect of fishing which allows few Clarinbridge oysters to reach lengths exceeding 80-90mm. In fact it is doubtful whether a true L_∞ could be determined for Clarinbridge oysters because the population is always in a truncated state as a result of fishing.

Stanley (1967) found that growth in scallops (*Pecten maximus*) in Northern Irish waters was indeterminate - that is, growth continued until death. Comfort (1957) noted the same phenomenon in certain other bivalves. Indeterminate growth is represented in the growth equation by a k value of greater than 1 (i.e., the slope of the Ford-Walford plot is greater than 45^{o}). Whilst indeterminate growth has not been demonstrated in Clarinbridge oysters it is suspected that it may occur. Oysters collected from unexploited populations on the west coast of Ireland have measured over 200mm in diameter and weighed up to 1400g (Whilde, in prep.) and on the basis of the slow growth rate observed at Clarinbridge it would appear that continuous growth over a long period would have been necessary to produce oysters of such dimensions. If growth in oysters is indeterminate the fitting of conventional growth formulae would fail because such formulae can only be fitted to animals exhibiting determinate growth (Stanley, 1967). Further investigations are necessary to clarify this point.

Orton and Amirthalingam (1930; cited by Comfort, 1957) estimated the maximum age of oysters (O. edulis) to be greater than 12 years. On the basis of the growth rates of oysters on the west coast of Ireland and the maximum sizes observed it is highly likely that the maximum age attained by the species is well in excess of 12 years.

Growth and Temperature

At Clarinbridge oyster growth generally starts in mid-March when the mean surface temperature reaches 8°C (Figure3 - Chapter III). Moderate growth continues until mid-June when the surface water temperature reaches approximately 15.5°C. While the temperature exceeds this threshold growth is relatively fast. The growth rate starts to decline at the end of September when temperature drops below 15°C and virtually ceases amongst adult oysters at the end of November until the following March when the temperature rises to 8°C again. On the other hand spat growth may continue slowly through the winter, stopping only for a short period during the coldest month, February. Rapid growth also starts earlier than in adults, usually in April when the temperature reaches 10°C and continues until the end of October when the temperature drops below the April threshold.

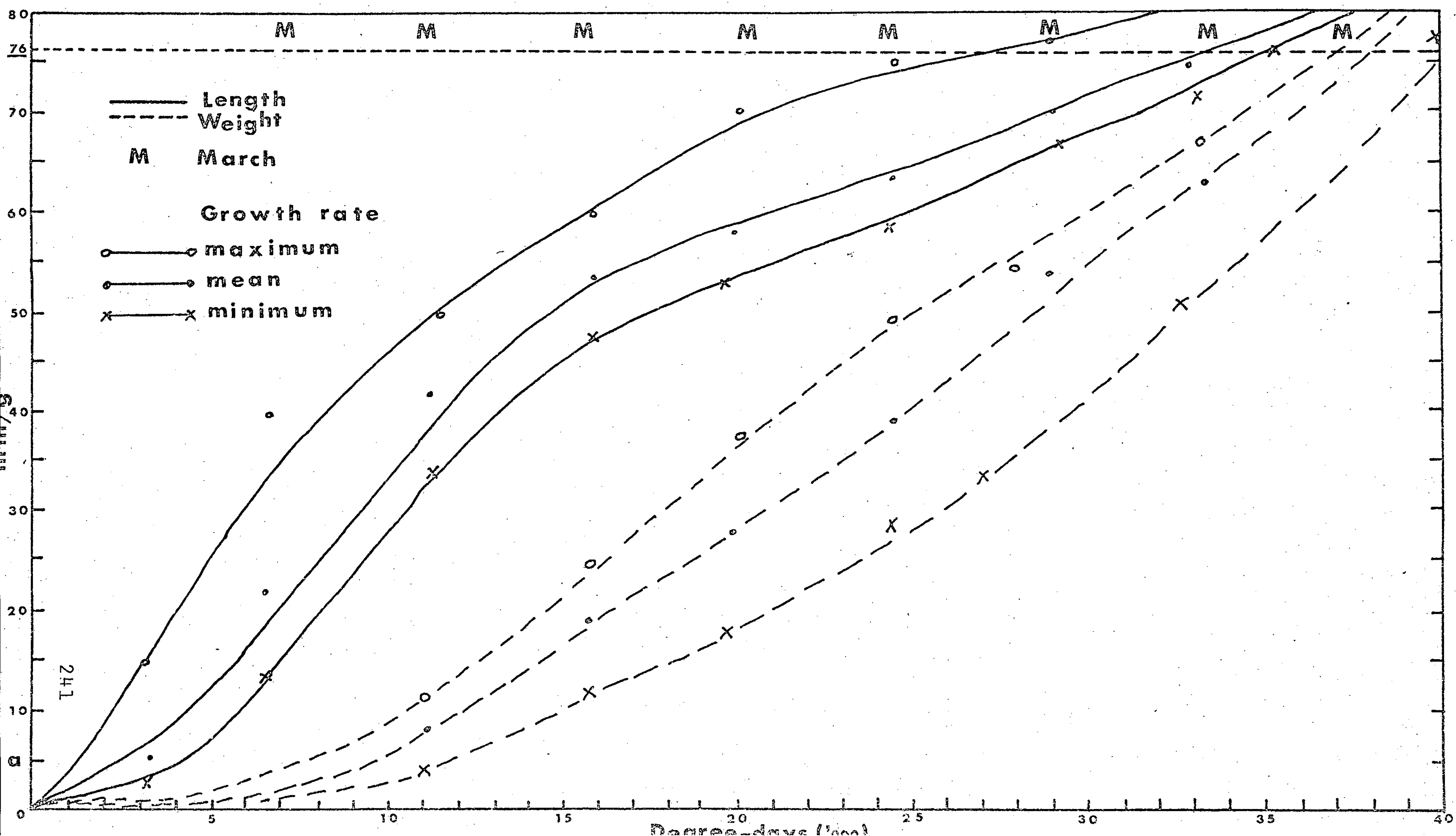
Walne (1958) generally found no growth in mean diameter in Tal-y-foel oysters until April, although he did find a slight increase in weight prior to this time in 1954. Growth was found to be general when the mean water temperature had risen to about 12°C and he suggests that "the beginning and the end of a season's growth, both in diameter and total weight is controlled by temperature," and that "once the critical limits, about 10°C to 12°C, are passed, other factors, of which food is probably the most important, determines growth rate. Korringa (1952) states that "careful weighing under water showed that as long as the water temperature remains above 10°C the deposition of shell material goes on. Only above 15°C was the diameter of the shells found to increase, somewhat earlier in young oysters, somewhat later in older oysters."

Thus it would appear that growth at Clarinbridge starts at a slightly lower temperature than in Wales and Holland, but in common with Dutch oysters, it is greatest when the water temperature exceeds approximately 15°C.

Figure 24 presents a composite graph of the growth rate of Clarinbridge oysters against the cumulative water temperature in degree-days. The cumulative temperature values were obtained by multiplying the mean monthly temperature by the number of days in the month.

The number of degree-days recorded at Clarinbridge (=Galway) each year is approximately 4,000. The value for the year March 1971 to March 1972, the period for which the growth data is presented,was just over 4,300. From Figure 24 it can be estimated that a fast-growing oyster requires 24,000 degree days (nearly 6 years) to reach commercial size, whilst an oyster growing at the 'mean' rate requires approximately 34,000 degree days (not shown on graph) or nearly 8 years to reach ring

FIGURE 24. A COMPOSITE GROWTH CURVE FOR CLARINBRIDGE OYSTERS IN RELATION TO THE TOTAL NUMBER OF DEGREE-DAYS FROM THE BEGINNING OF THE EXPERIMENT.



size in the conditions which prevailed in Clarinbridge during 1971. On the same basis it would take an 'average' Clarinbridge oyster 8 years to reach a weight of 60g. However, it must be remembered that these growth periods include periods when the temperature is below the growth threshold and, therefore, the absolute number of degree-days required to produce a given amount of growth is less than indicated in Figure 24. Table 28a (2) in Chapter IV indicates that there are, in fact, 1000 to 1500 degree-days at Clarinbridge during the period when the water temperature exceeds the growth threshold.

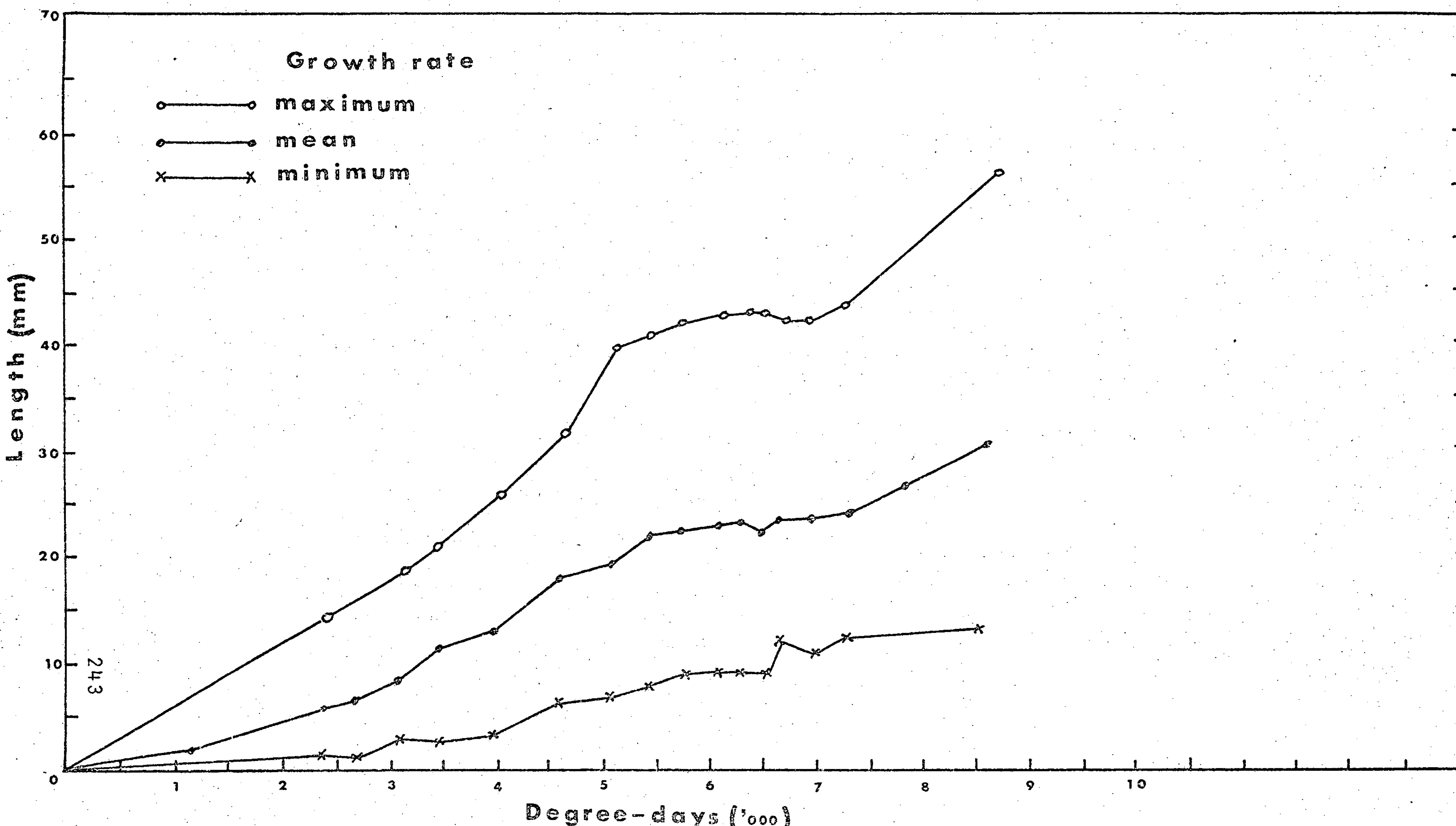
The slow growth rate illustrated in Figure 24 was recorded in a year when there were more than the average number of degree-days recorded. This suggests that temperature is not the controlling factor in growth and tends to confirm Walne's assertion (quoted earlier) that growth is controlled by other factors, possibly food, once a specific temperature threshold has been exceeded.

Figure 25 presents the growth of 1970 spat in relation to degree-days.

Growth and Tidal Level

Clarinbridge oyster buyers store their oysters for three months to two years on intertidal layings where they can be retrieved easily for sale. Those oysters which are not sold by the end of April following the fishing season are generally left on the layings until the following September or later, with the expectation that they will grow. The following experiment was conducted in order to provide information for the

FIGURE 25. THE MEAN LENGTH INCREMENT OF CLARINBRIDGE SPAT IN RELATION TO THE TOTAL NUMBER OF DEGREE-DAYS FROM THE BEGINNING OF THE EXPERIMENT.



buyers about the effect of exposure on their relaid oysters.

Three trays, each containing 100 oysters of modal size 61-65mm, and 1 tile bearing 1970 spat, were placed at three levels on the shore at the experimental shore laying (Map 8), directly opposite the most productive part of the oyster fishery. The three levels were: (i) low neap tide (winter); (ii) normal low spring tide (winter); and (iii) extreme low spring tide (winter). It was not possible to compute the amount of exposure at each level as Walne (1958) or Baird (1966) were able to do in similar experiments. The adult oysters were measured to the nearest millimetre and the spat to the nearest 0.1mm at the end of March 1971 and again at the end of February 1972. The results are tabulated below. The figures in brackets are the increments recorded by Walne (1958) in similar experiments carried out in 1949 and 1951 respectively. Walne gave the degrees of exposure at the levels employed in his experiments (the same as those employed at Clarinbridge) as 14% (low water neap tide level), 5% and 1.5% respectively.

TABLE 50

THE GROWTH OF CLARINBRIDGE OYSTERS AT VARIOUS SHORE LEVELS

(a) Adults

	Low (neap)	Low (spring)	Low (extreme spring)
Date	Mean diameter	Mean diameter	Mean diameter
23/3/1971	69.0	67.0	67.5
27/2/1972	70.9	75.3	71.9
Relative Increase %	2.8 (10.6) (10.4)	12.4 (16.4) (31.8)	6.5(18.6) (30.6)

(b) Spat

	Low (neap)	Low (spring)	Low (extreme spring)
23/3/1971	5.9	6.5	5.7
27/2/1972	14.1	18.0	20.7
Relative Increase %	139.3	177.8	266.7

Both adults and spat grew poorly at the upper shore level. However, the adults in the mid-shore tray showed a higher relative increase than those held at the lowest station. In contrast spat growth was greatest at the lowest level.*

Walne (1958) also recorded poor growth at the top level, but he found that the growth rates at the other two levels were similar, in contrast to the results obtained at Clarinbridge. These differences may arise from a different combination of exposure times resulting from the differences between the slopes of the shores at Clarinbridge and Tal-y-foel.

Minor Growth Experiments

(i) Growth at the Surface

In order to test the effect of holding oysters near the surface a group of fifty 36-40mm oysters was held in a plastic mesh bag suspended 30cm below the surface of the water. A control group of fifty oysters was placed on the seabed in a similar bag. Each set of oysters was weighed at monthly intervals and the mean growth rates are plotted in Figure 26.

Figure 26 shows that growth at the surface was considerably faster than on the seabed. However, the oysters held at the surface suffered the disadvantage of heavy fouling with algae and bryozoans. The low surface salinities recorded in the winter did not appear to affect their growth adversely.

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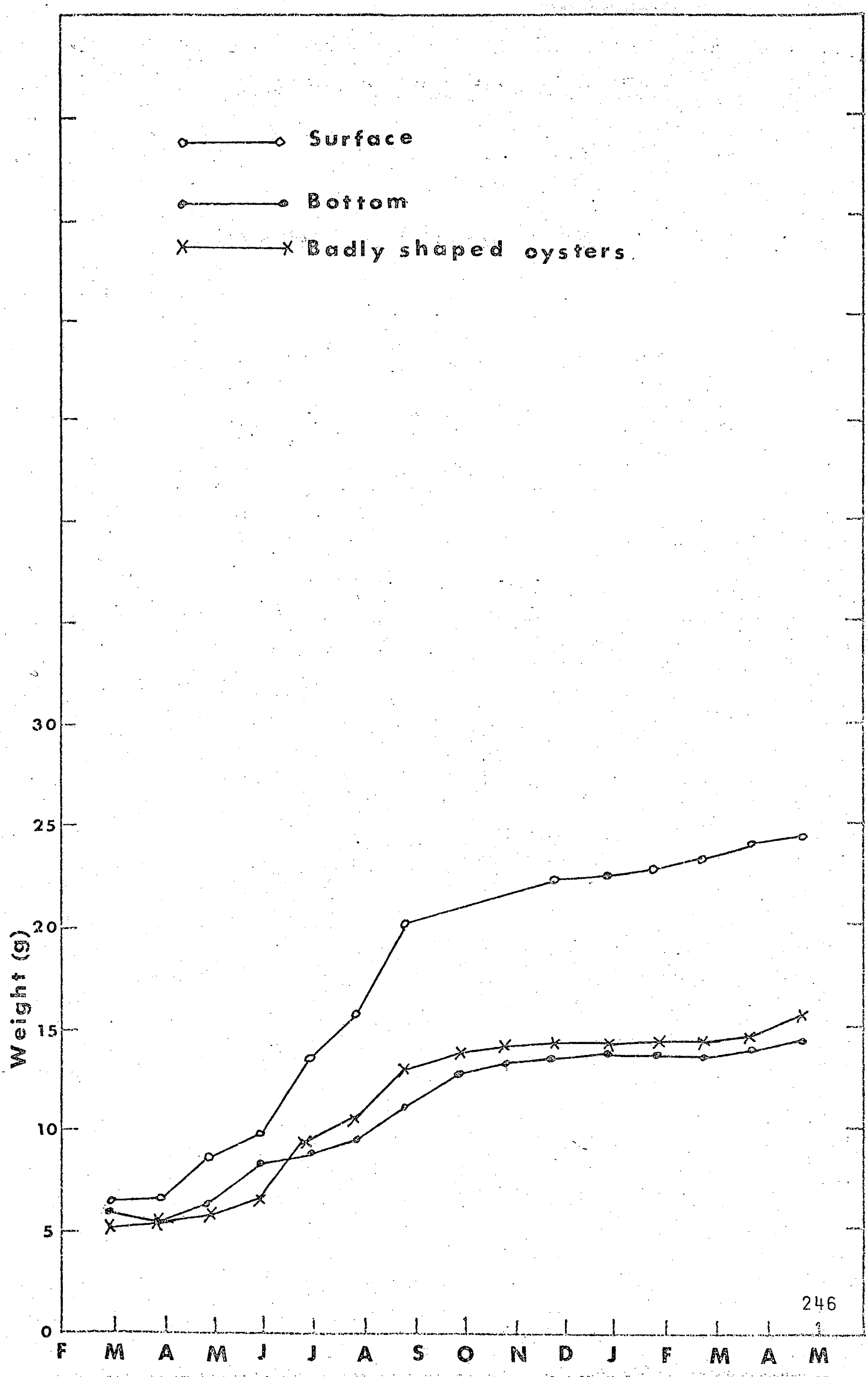
* Although the relative increments differ considerably between the three spat groups there is no significant difference between their initial and final mean sizes at the 95% level.

FIGURE 26

A COMPARISON OF THE MEAN WEIGHT INCREMENTS OF OYSTERS HELD ON THE SEA BED WITH (a) MIS-SHAPED OYSTERS, (b) OYSTERS HELD AT THE SURFACE.



(ii) <u>Growth of Badly Shaped Spat</u>

The weight increase of a group of fifty badly-shaped oysters held in a bag on the seabed was monitored at monthly intervals to determine whether the initial shape affected their growth rate. Since their initial mean weight was similar to that of the two groups in the experiment described previously the results are also plotted in Figure 26. This shows clearly that the badly shaped oysters grew as well as the controls and, in addition, within a year most of the group had developed into well shaped oysters.

7. Mortality

Mortality estimates were made as an adjunct to the growth studies described earlier. Since most of the observations were made on oysters held in bags, and therefore free from serious predation, the estimates must be considered as 'background mortality' (Walne, 1961) rather than total natural mortality.

Spat Mortality

Spat mortality during the first month of life ranged from 58% to 90% in 1970 and 1971 (see Chapter III). From September until the following March it dropped to approximately 26%. The mean annual mortality of Clarinbridge spat was 78% to 95%, somewhat higher than that recorded by Walne (1958) - 66% to 92%.

The mortality of 1970 spat held in bags on the oyster bed was 33.3% between March 1971 and March 1972, while the corresponding mortality of spat at the control laying was 20.9%.

Adult Mortality

The mortality in various size groups held in bags on the oyster bed is given in Table 51 below. The mortality rate of the shore control groups is also presented for the period March 1971 to January 1972. The average mortality rate of the equivalent seabed size classes for the period March 1971 to January 1972 was 23.5%.

TABLE 51

OYSTER MORTALITY AT THE CLARINBRIDGE PUBLIC OYSTER FISHERY IN 1971-1972

Size class	Annual mortality %	Control
20-30	36	
26-30	28	
31-35	31	26
36-40	27	
41-45	27	29
46-50	29	
51-55	17	14
61-65	22	28
66-70	35	
71-75	21	34
76+	18	
Average	25.9	26.2

It would appear from these experiments that the background mortality is similar in all size groups examined. It must, therefore, be concluded that any differential mortality between size classes in unprotected populations is a function of their susceptibility to predators, disease or smothering. The similarity between the mortality rates of bagged oysters on the seabed and those of the unprotected shore control groups suggests that the only major predators present in the area (shore crabs - Carcinus maenas) have little or no effect on oysters larger than 31mm in diameter.

The average monthly mortality for the whole experimental group is compared with the mean monthly temperature in Table 52. This shows that mortality is negligible during the autumn and winter and highest in the spring. This observation is in keeping with Waugh's (1954) observation that the majority of oysters that are weak do not die until the temperatures start to rise.

TABLE 52

COMPARISON OF THE MEAN MONTHLY SURFACE-WATER TEMPERATURE AND THE MEAN MONTHLY MORTALITY (%) OF CLARINBRIDGE OYSTERS

Month	Mean Monthly Temperature ^{0}C	Mean Monthly Mortality %
A	10.4	1.1
M	12.7	7.5
J	14.0	4.6
J	17.0	3.6
A	17.1	4.0
S	16.7	1.8
O	13.5	1.1
N	10.7	0.5
D	8.6	0.5
J	6.2	0.6
F	6.9	0
M	7.2	0.5
Total		25.9

Survivorship Curve

From the foregoing 'background' mortality data, in combination with a knowledge of the growth rates of the various size classes (presented earlier) it is possible to construct a general survivorship curve for Clarinbridge oysters, under the conditions prevailing in 1971-1972. Figure 27 presents a composite survivorship curve for 1000 newly settled spat. The survival rate of Clarinbridge oysters is slightly lower than that of Tal-y-foel oysters studied by Walne. He found that approximately 1.5% survived to the age of 7½ years, whereas at Clarinbridge only 0.6% appear to survive to that age. Since Walne's oysters probably reached commercial size (76mm) in 3½ to 4½ years (interpolated from Walne's data, 1958), the difference in survival rates is of considerable significance because 20% of his original population will reach commercial size, whereas only 0.6% of the Clarinbridge stock will reach this stage at 7½ years old.

Mortality and Tidal Levels

The mortality rate of oysters laid at various levels of the shore (see earlier section on growth) is presented in Table 53 below.

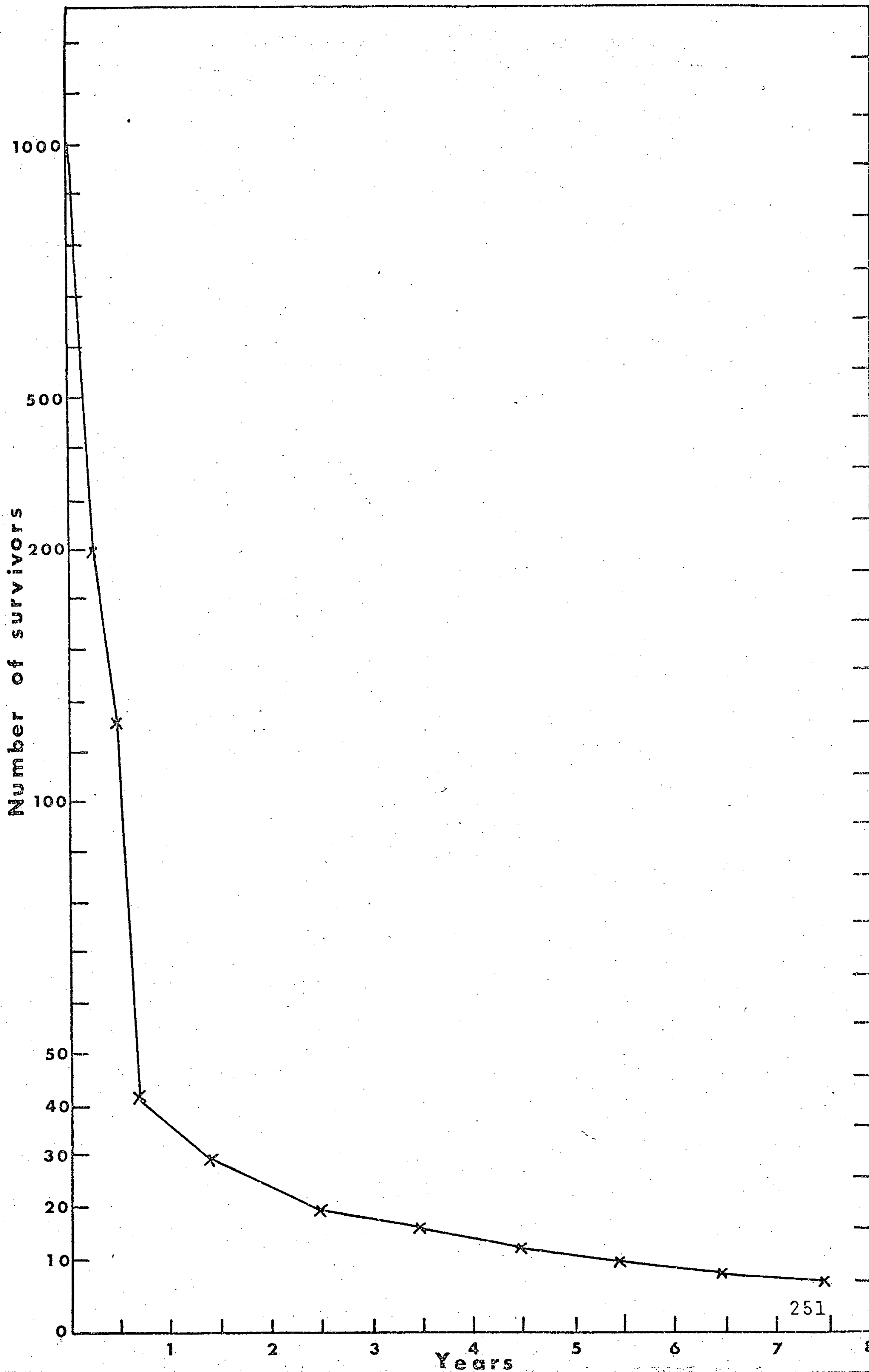
TABLE 53

MORTALITY (%) OF OYSTERS LAID AT DIFFERENT TIDAL LEVELS DURING 1971

	Date	Low (neap)	Low (spring)	Low (ES)
Adults	28/3/1971 27/2/1972	49%	41%	42%
Spat	28/3/1971 27/2/1972	59%	62%	31%

FIGURE 27

A SURVIVORSHIP CURVE FOR CLARINBRIDGE OYSTERS.



These figures suggest that, while exposure affects the growth of adults, it has little effect on their survival. On the other hand, almost continuous submersion appears to have reduced the mortality rate of spat which are probably less resistant to the pounding of waves and scouring by suspended particles (Shelbourne, 1957).

Mortality and Production

Table 54 indicates how mortality affected the standing crop of the experimental oyster groups and, ultimately, the level of overall production. In spite of an increase in the mean weight and mean size of individuals in the experimental population there was a general decline in the total standing crop (both in terms of weight and length) as a result of mortality.

TABLE 54

THE EFFECT OF MORTALITY ON THE STANDING CROP OF THE EXPERIMENTAL OYSTER GROUPS EMPLOYED AT CLARINBRIDGE DURING 1971 TO 1972

(a) Weight				Change
Initial Number	1,000	Final Number	741	-25.9%
Initial Total Weight	29,548g	Final Total Wt.	26,952	- 8.8%
Initial Mean Weight	29.55g	Final Mean Wt.	36.37g	+23.1%
(b) Size				**Change**
Initial Number	700	Final Number	523	-25.3%
Initial Total Length	41,064mm	Final Total Lgth.	32,382mm	-21.1%
Initial Mean Length	58.66mm	Final Mean Lgth.	61.92mm	+ 5.56%

The actual changes in weight, relative to the actual monthly mortality are given in Table 55.

TABLE 55

THE CHANGE IN WEIGHT WITH MORTALITY OF THE EXPERIMENTAL OYSTERS DURING 1971-1972

Month	Number	Total Weight (g)	Mean Weight (g)
M	1,000	29,548	29.55
A	989	27,958	28.27
M	914	26,722	29.24
J	868	25,687	29.59
J	831	25,971	31.25
A	791	26,099	32.99
S	773	27,605	35.71
O	762	27,517	36.11
N	757	27,531	36.37
D	752	27,511	36.58
J	746	26,980	36.17
F	746	26,916	36.08
M	741	26,952	36.37

These observations suggest that the growth rate of Clarinbridge oysters is insufficient to compensate for the reduction in standing crop resulting from 'background' mortality. Therefore, a steady state population in terms of standing crop, could only be maintained by the regular recruitment of spat into the adult stocks. In the years after a poor spatfall it can be predicted, therefore, that the standing crop will decline as a result of the imbalance between growth and mortality

8. Condition

Oyster condition was monitored at monthly intervals from March 1970 to July 1972. Both the wet Volume Condition

Index (Grave, 1912, cited by Westley, 1961; Baird, 1958; Millar, 1961) and the Dry Weight Condition Index (e.g., Walne, 1970) were estimated using the following equations:

$$\text{Wet Volume Condition Index} = \frac{\text{Volume of meat (ml)}}{\text{Volume of shell cavity (ml)}} \times 100$$

$$\text{Dry Weight Condition Index} = \frac{\text{Weight of dried meat (g)}}{\text{Volume of shell cavity (ml)}} \times 1000$$

The first index is most realistic as far as an oyster dealer is concerned because he is interested in 'fatness' of the meat relative to the size of the shell cavity. However, the second index is considered to be more precise because fluctuations in conditions cannot be masked by the variable amounts of water contained in oyster meat (Walne, 1970).

Sixty commercial oysters, averaging approximately 60 grms each were taken from the fishery each month and divided into four groups of fifteen. Epifauna and silt were removed from every oyster and the following parameters were determined for each group:

a. total weight;
b. total volume (by displacement, Baird, 1958);
c. shell weight;
d. shell volume;
e. meat weight (after the removal of excess water on blotting paper);
f. meat volume (by direct measurement);
g. dry meat weight (by drying to constant weight at 70°C).

The two equations can now be expressed in terms of the parameters indicated above:

$$\text{Wet Volume Condition Index} = \frac{f}{b-d} \times 100$$

$$\text{Dry Weight Condition Index} = \frac{g}{b-d} \times 1000$$

The percentage solids composition of the meats could also be calculated from the above-mentioned parameters and this is given by:

$$\frac{g}{e} \times 100$$

Figure 28 presents the seasonal changes in the condition and percentage solids of Clarinbridge oysters between March 1970 and July 1970. The points on the line are the mean values of the four groups examined each month and the vertical lines represent the range of values within each sample. Figure 29 presents the coefficients of correlation (r) between (a) the mean Dry Weight Condition Index and the mean Wet Volume Condition Index; (b) between the mean Wet Volume Condition Index and the mean Percentage solids; and (c) between the mean Dry Weight Condition Index and the mean Percentage Solids. The calculated regression lines for the various combinations of parameters are also given.

The strong correlation between the two condition indices suggests that Baird's (1958) confidence in the Wet Volume Condition Index is well founded, provided that large samples are used to overcome the wide inherent variations within the samples. It does not appear that variations in water content masked any changes in the condition of Clarinbridge oysters.

Seasonal Changes in Condition and Percentage Solids

At Clarinbridge condition appears to be lowest in the winter and highest in the summer, peaking at approximately 55 (W.V.C.I.) and 135 (D.W.C.I.) in August. This was also

FIGURE 28

SEASONAL CHANGES IN THE CONDITION INDICES AND PERCENTAGE SOLIDS OF CLARINBRIDGE OYSTERS.

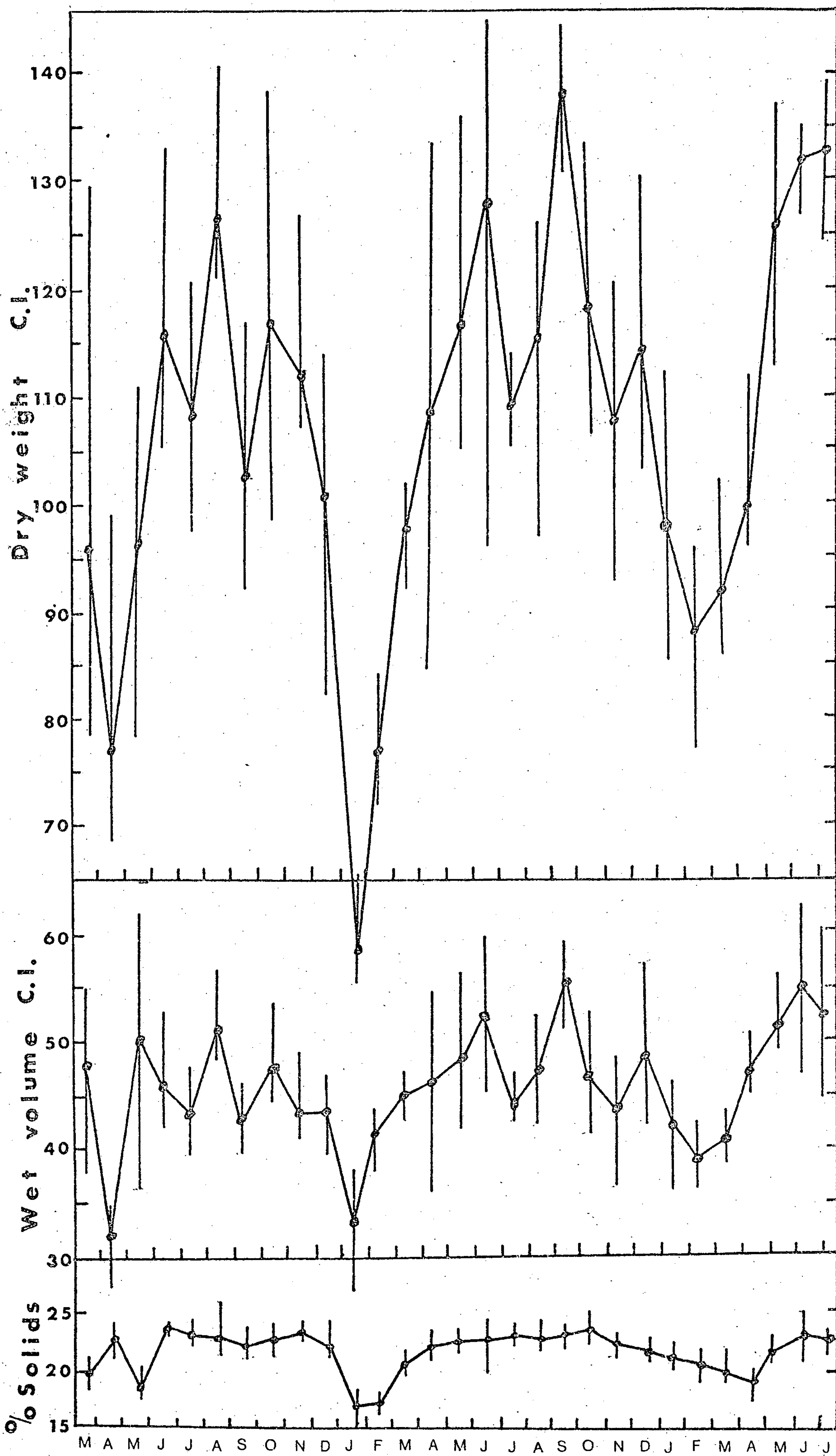
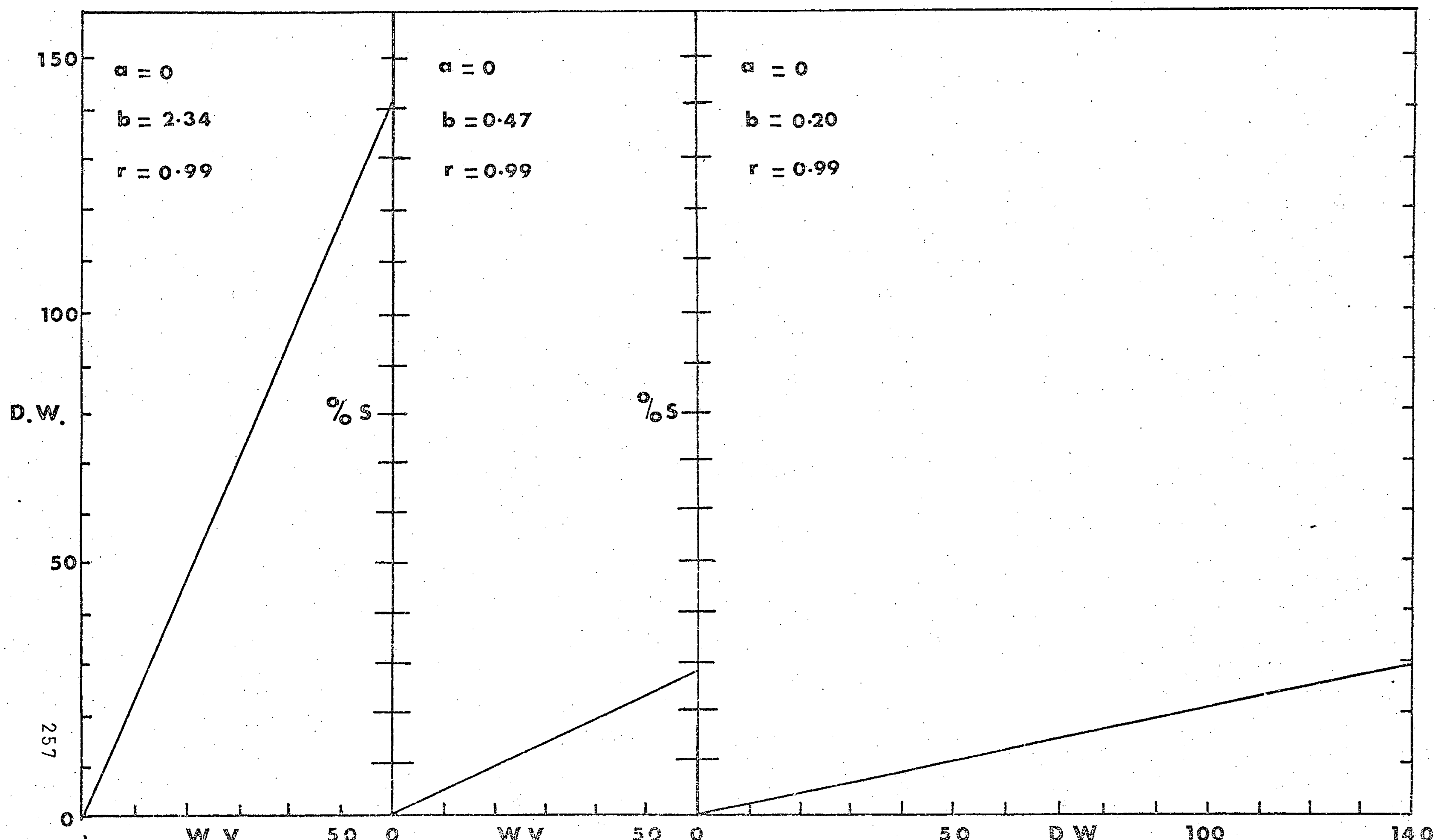


FIGURE 29. THE RELATIONSHIP BETWEEN INDICES OF CONDITION AND PERCENTAGE SOLIDS OF CLARINBRIDGE OYSTERS.



generally the case with oysters from various parts of England and Wales which were tested by Walne in 1961 (Walne, 1970). The low values recorded in January and February 1971 are anomalous because they were determined with oysters which had been obtained from a local oyster buyer who had stored them intertidally for several weeks. As will be shown later, prolonged exposure resulting from relaying in the intertidal zone can cause a rapid decline in oyster condition.

The percentage of solids remained fairly steady throughout the study period at between 21.5% and 23.5%, dropping below 20% only occasionally - usually at the beginning of the growing season.

Condition and Tidal Level

The condition indices of oysters employed in the previously described exposure experiment were determined at the end of the experiment and in Table 56 below they are compared with those of control groups taken from the oyster bed at the beginning and end of the experiment.

Whilst there was only a slight drop in the condition indices of oysters held at extreme low water spring mark, compared with the controls, the two groups sited higher on the shore showed a considerable decline in condition. A considerable decline in the percentage solids of all the shore groups was also recorded. This loss in condition and solids content may have resulted from reduced feeding as a result of increased exposure, or from reduced feeding owing to the greater turbidity of the relatively turbulent and shallow water covering the trays.

TABLE 56

THE EFFECT OF EXPOSURE ON CONDITION INDICES AND PERCENTAGE SOLIDS OF OYSTERS AT CLARINBRIDGE

	Wet Volume C.I.	Dry Weight C.I.	% Solids
Control March 1971	45.0	97.7	20.2
Low (neap)	30.3	60.7	15.6
Low (spring)	33.3	53.3	15.0
Low (extreme spring)	40.0	71.2	16.3
Control February 1972	39.7	88.8	20.2

Condition and Spawning

Spawning appeared to have little effect on the condition of Clarinbridge oysters which were generally in peak condition during the main breeding season (July and August). In 1970 peak larvae release coincided with peak condition at the beginning of August, but in 1971 peak condition occurred towards the end of August, after peak larvae release. Several oysters used in the condition tests were spent or brooding larvae but apparently their condition in no way depressed the mean values of the condition indices. These observations are in keeping with those of Walne (1964) who found that spawning in British oysters had little effect on their condition. In contrast Millar (1961) found that the condition of oysters in West Loch Tarbet, Scotland, 'dropped sharply after spawning in the summer' in 1953. However, Millar also pointed out the important period of fattening in August and September is indicated by the rising condition factor at that time - when spawning, according to his larvae production figures, is still occurring. This apparent contradiction suggests that if the level of food available during the breeding season is high, condition will not be affected by spawning.

Condition and Marketing

According to Korringa (1956b) cited by Walne (1970), a good quality commercial oyster has a Dry Weight Condition Index of approximately 100, which is equivalent to approximately 45 for the Wet Volume Condition Index at Clarinbridge. Figure 30 shows that in 1970 such indices were exceeded by 82% and in 1971 by 75% of the samples examined. However, reference to Figure 30 will show that the samples which had indices lower than these satisfactory values usually occurred during the winter months when oysters are 'in season'. The highest indices were recorded in the summer when the oysters are rendered unacceptable (although not unpalatable) by their breeding activities. Therefore, the times when Clarinbridge oysters are in good condition and are acceptable to the market appear to be restricted to October and sometimes September and November or possibly May.

Standing Crop and Production

The standing crop of each 5mm size class at the time of each grab survey is presented in Tables 57a and b, in terms of total weight and meat weight. The total estimates are based on the mean values for each size-class interpolated from

FIGURE 30. CUMULATIVE CURVES SHOWING THE PROPORTION OF SAMPLES WHICH EXCEEDED SUCCESSIVE DRY WEIGHT CONDITION INDEX VALUES IN 1970 AND 1971.

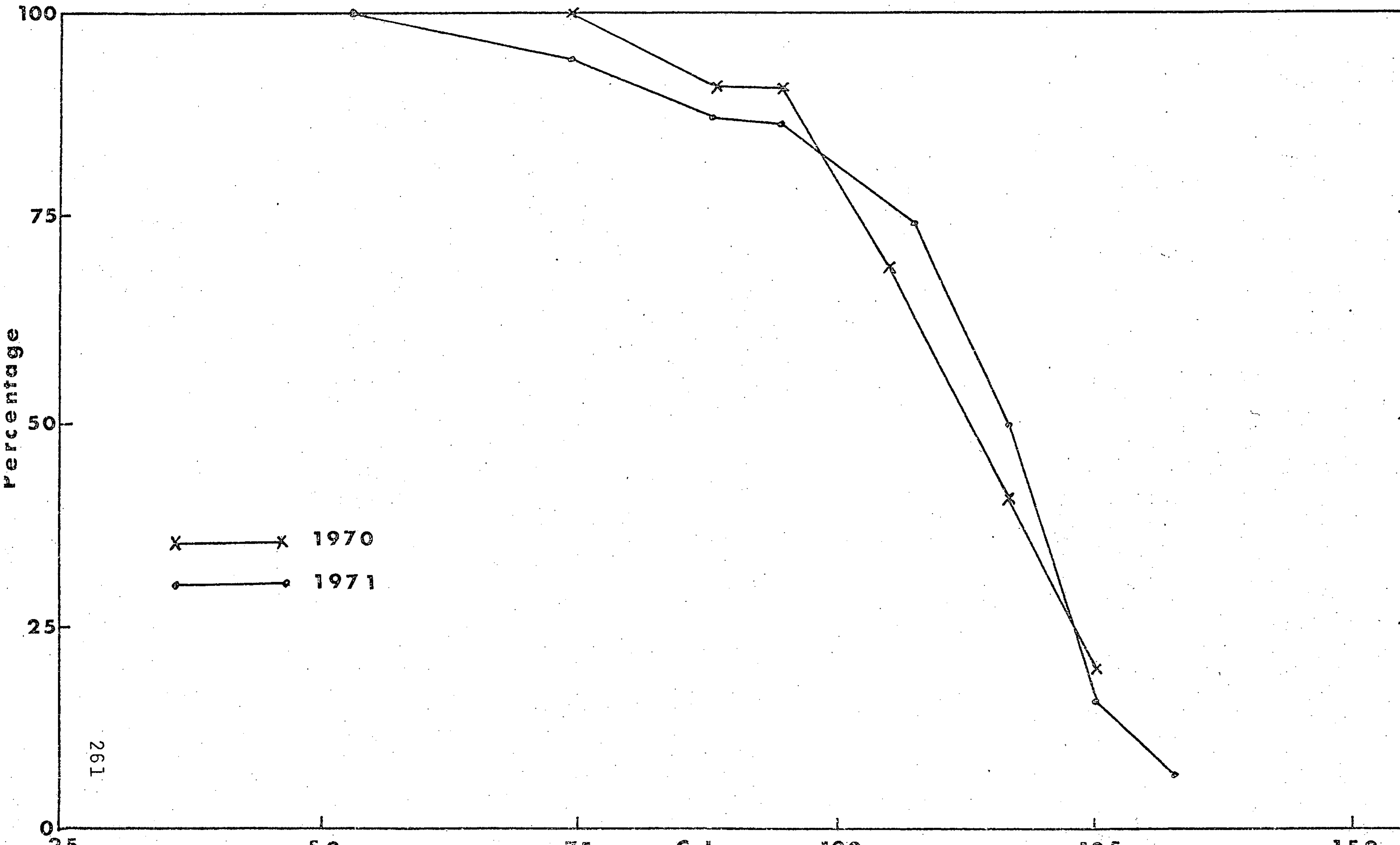


TABLE 57(a)

THE STANDING CROP AT THE CLARINBRIDGE PUBLIC OYSTER FISHERY
1969 TO 1972

Size Class	Numbers (/110 ha) August 1969	November 1970	April 1971	November 1971	January 1972
0-5	0	0	0	82,467	0
6-10	0	0	27,951	54,747	110,000
11-15	15,488	13,959	27,951	220,374	110,000
16-20	107,008	438,570	498,036	164,934	165,000
21-25	137,984	1,115,730	775,005	164,934	522,500
26-30	199,232	1,354,320	996,919	247,401	330,000
31-35	183,744	1,952,280	1,300,992	357,588	522,500
36-40	321,024	1,194,930	996,919	494,802	330,000
41-45	520,256	537,570	719,950	467,775	605,000
46-50	826,496	438,570	470,002	604,989	687,000
51-55	612,480	397,980	387,000	632,709	1,155,000
56-60	1,010,240	378,180	276,019	659,736	1,100,000
61-65	765,248	557,370	332,024	769,923	1,320,000
66-70	994,048	458,370	830,060	689,456	660,000
71-75	718,784	397,980	387,926	715,176	660,000
76-80	367,488	298,980	276,969	164,934	247,500
81-85	199,232	139,590	166,012	302,841	220,000
86-90	15,488	80,190	27,951	82,467	27,500
91-95	45,760	0	0	0	0
96-100	0	19,800	0	54,747	0
Total	7,040,000	9,900,000	8,497,686	6,930,000	8,772,500

TABLE 57(b)

THE STANDING CROP AT THE CLARINBRIDGE PUBLIC OYSTER FISHERY
1969 TO 1972

	Total Weight (kg/110 ha)				
Size Class	August 1969	November 1970	April 1971	November 1971	January 1972
0-5	0	0	0	41	0
6-10	0	50	28	55	110
11-15	23	21	42	331	165
16-20	21	877	996	330	330
21-25	345	2,789	1,938	412	1,306
26-30	598	4,063	2,991	742	990
31-35	827	8,785	5,855	1,690	2,351
36-40	2,408	8,962	7,477	3,711	2,475
41-45	5,463	5,645	7,560	4,912	6,352
46-50	11,571	6,140	6,851	8,772	9,969
51-55	12,250	7,580	7,740	12,654	23,100
56-60	28,287	10,589	7,729	18,473	30,800
61-65	28,314	20,623	12,285	28,487	48,840
66-70	46,720	21,543	39,013	32,310	31,020
71-75	41,330	22,884	22,306	41,123	37,950
76-80	26,092	21,228	19,665	11,710	17,573
81-85	16,437	11,516	13,696	24,984	18,150
86-90	1,394	7,217	2,516	7,422	2,475
91-95	4,118	0	0	0	0
96-100	0	1,782	0	4,927	0
Total	226,198	162,244	158,688	203,086	233,956

TABLE 57(c)

THE STANDING CROP AT THE CLARINBRIDGE PUBLIC OYSTER FISHERY
1969 TO 1972

	Meat Weight (Kg/110 ha)				
Size Class	August 1969	November 1970	April 1971	November 1971	January 1972
0-5	0	0	0	8	0
6-10	0	0	3	6	11
11-15	3	3	6	44	22
16-20	32	132	149	50	50
21-25	41	335	233	50	157
26-30	80	542	399	99	132
31-35	110	1,171	781	225	314
36-40	289	1,075	897	445	297
41-45	676	699	936	608	787
46-50	1,488	789	846	1,089	1,238
51-55	1,531	948	968	1,581	2,888
56-60	3,637	1,362	994	2,375	3,960
61-65	3,597	2,620	1,561	3,619	6,204
66-70	5,964	2,750	4,980	1,501	3,960
71-75	5,319	2,945	2,871	5,292	4,884
76-80	3,344	2,721	2,520	1,501	2,252
81-85	2,112	1,480	1,760	3,210	2,332
86-90	180	930	324	956	319
91-95	531	0	0	0	0
96-100	0	230	0	635	0
Total	28,934	20,732	20,228	25,918	29,807

the length-weight regression line given earlier. The meat weight values are based on measurements made on a sample of 300 oysters in October 1970. The overall total weight : meat weight ratio of approximately 7.8:1 determined from the sample changed only slightly throughout the study period (maximum 7.8 ±0.5), but generally not to an extent that would seriously affect the values in Table 57. It will be noted that the total standing crop appears to have remained fairly constant throughout the study period, the largest recorded being only 1.4 times the size of the smallest, in spite of the changes in population structure which occurred during this period (Table 57a).

The net production was calculated for the period April 1971 to November 1971, thereby excluding the effects of fishing on the estimate (Table 58). The April standing crop was calculated by multiplying the mean weights of each of the experimental size classes by the number of oysters in each class in the population (Table 57a). The November standing crop was calculated in the same way using the November mean size values and the April numbers less the numbers lost to background mortality (based on the mortality figures presented in Table 51). Thus:

$$\text{Production} = \underset{(\text{kg/ha})}{1524} - \underset{(\text{Kg/ha})}{1469} = \underline{55\ \text{Kg/ha}}$$

Since the period April to November is the main period of growth and mortality the annual productivity can be given as approximately 55Kg/ha/an or 6050 kg/an for the whole oyster bed for 1971. These values are equivalent to meat productivity of 7Kg/ha/an or 770Kg/an for the whole fishery.

The expected standing crop of commercial oysters on the fishery in November was calculated from the data presented in Table 57. In addition to the standing crop of commercial oysters indicated in Table 57, 10.5%* of the April stock of 71-75mm oysters with a mean weight of 75 grms (the average of the mean November weights of the 71-75mm and 76+mm groups) were added to present a more realistic estimate of the standing crop of commercial oysters. This figure is compared with the observed standing crop of commercial oysters in November, the December landings and the production in Table 58 below.

TABLE 58

THE STANDING CROP AND LANDINGS OF COMMERCIAL OYSTERS AND THE PRODUCTION AT THE CLARINBRIDGE PUBLIC OYSTER FISHERY IN 1971

Month	Total Weight (kg)	Meat Weight (kg)
April	38,267	4,906
November (estimated)	37,361	4,550
November (observed)	49,043	6,302
December (landings)	22,000	2,800
Total Estimated Net Production	6,050	700

The discrepancy between the estimated and observed values for the November figures arise from: (a) the inaccuracy of the grab surveys; and (b) the possibility that the commercial oysters on the seabed grew better and suffered a lower mortality than the experimental oysters which were held in plastic mesh bags.

The landings in December 1971 amounted to approximately

*The overall recruitment of 71-75mm oysters to the 76+ group. cf. Table 47 which gives the percentage recruitment of survivors.

22,000Kg total weight and almost 2,800Kg meat weight. While these figures are less than the observed and calculated estimates of available commercial oysters they are nearly four times greater than the production estimates. This suggests that the Clarinbridge oyster stocks were overfished in 1971. This apparent overfishing may have been compensated to a limited extent by the recruitment of spat which could not be quantified - although this is unlikely in the light of the poor spatfall in 1971 (see Chapter IV). Alternatively the production value may be an overestimate because natural mortality, other than background mortality, could not be incorporated into the estimate (except for spat), suggesting that the level of overfishing indicated above may be an underestimate.

Finally, if the production had been taken as the difference in the total standing crop between April and November (44,398Kg) then the stock would have been underfished by 50%. However, since the accuracy of the grab survey population estimates is limited the production estimates based on one grab survey (April) may be more reliable than those based on two surveys.

CHAPTER VI

FACTORS LIMITING OYSTER PRODUCTION

VI. FACTORS LIMITING OYSTER PRODUCTION

Oyster production is limited by a variety of factors such as predation, competition, parisitism, disease, pollution and environmental disturbance. In this chapter each of these factors will be considered in relation to the Clarinbridge Public Oyster Fishery.

Unfortunately extensive data relating to most of the factors listed above are not available. However, sufficient information is presented to form a basis for management proposals which will be discussed in Chapter VII.

Before discussing some of the factors which adversely affect oyster production at Clarinbridge it is pertinent to mention some of the pests and problems which afflict English and other European oyster fisheries but which are absent from Irish waters. Three pest species are of particular importance and all were introduced accidentally into Europe from North America and New Zealand. These are, firstly, the boring American whelk tingle (Urosalpinx cinerea Say) which causes serious losses of spat on several English oyster fisheries (Hancock, 1959); secondly, the New Zealand barnacle (Elminius modestus) which, unlike native barnacles, settles at the same time as oysters and, therefore, competes for limited settling space; and thirdly, the slipper limpet (Crepidula fornicata) which competes with oysters for space and food (Walne, 1956b). Although the latter species has not been reported from Galway Bay in recent times, Sykes (1905) noted that a number of specimens were found in consignments of Essex oysters transplanted in Ballinakill Harbour at the turn of the century. Apparently the species did not flourish.

Serious industrial and domestic pollution, such as is currently affecting oyster fisheries in Brittany (Madec, pers. comm.) is absent from the coastal waters of western Ireland at the present time. However, this favourable situation is now being threatened by industrialisation and urban expansion and the present purity of the water in areas such as Galway Bay may soon be placed in serious jeopardy (Smith, 1972).

Predators

Ostrea edulis, by virtue of its life cycle, is vulnerable to a multitude of predators. The predators of the planktonic larvae were mentioned in Chapter IV and will not be discussed again here.

The major known predators of settled oysters which occur at Clarinbridge are the common starfish (*Asterias rubens* L.), the shore crab (*Carcinus maenas* L.) and the European rough tingle (*Ocenebra erinacea*). Other species which are known to consume oysters also occur but their effects on the oyster stocks are either negligible or impossible to assess. These include the spiny starfish (*Marthasterias glacialis*) (Hancock, 1969b) which has been recorded occasionally at the western end of the oyster grounds, the common whelk (Buccinum undatum) (Hancock, 1960), the dog-whelk (Nucella lapillus L.), flatworms (unidentified) which may kill newly settled spat, the pea-crab (Pinnotheres pisum) which occurs in mussels at Clarinbridge but is rarely found in oysters, and birds such as the oyster-catcher (Haematopus ostralegus L.) which can cause severe damage to oysters laid intertidally.

1. Starfish *(Asterias rubens L.)*

The common starfish is an important predator of oysters where the latter occur in large concentrations and in areas where alternative 'preferred' foods are not available. Related species in the United States (Asterias forbesi Desor; Galstoff and Loosanoff, 1939) and Canada (Asterias vulgaris Verril; Medcof, 1961) also cause serious damage to commercial stocks where they are not effectively controlled. In Holland starfish (A. rubens) are abundant but are not a serious pest on oyster grounds because they 'prefer' mussels (Mytilus edulis L.) which are abundant in the area (Korringa, 1951b). In Britain large concentrations of starfish occur on the Essex oyster beds. Here, however, they appear to have become beneficial to the oyster stocks because they 'prefer' to feed on another pest (Crepidula fornicata) (Hancock, 1958), which since its accidental introduction in about 1880 (Hancock, 1969b) has become a serious competitor for space and food.

Starfish at Clarinbridge

(a) Distribution and Density

Starfish occur on all the public oyster grounds at Clarinbridge, west of a line running south from Keave (Map 4, Chapter II). They are particularly abundant on the private St. George oyster grounds and, because the population on this fishery appears to be a reservoir for the starfish which infest the public fishery, close attention is paid to this population in the following sections.

The density of starfish on the private fishery was estimated by counting the starfish inside a grid of known area (see later) with the aid of S.C.U.B.A. Dredge surveys showed that starfish were fairly evenly distributed over the private fishery and that the density of starfish inside the grid was reasonably representative of the whole area. The average density of starfish in the grid was 0.3 per square metre between the end of July and the end of November 1971. The density of starfish on the public fishery was much lower and could not be assessed directly using a grid. Instead an indirect estimate was made by comparing the diving effort required to collect starfish on the two fisheries. In July 1971 it took one diver one hour to collect 245 starfish on the private fishery and one hour to collect 50 starfish on the public fishery, working at the same pace in both areas (visibility and current strength were similar in both areas). These observations suggest that the density of starfish on the public fishery was approximately one-fifth of that on the private fishery - i.e., 0.06 per square metre.

These densities correspond closely to those noted by Hugh-Jones (1969) who observed 0.3 to 0.5 starfish per square metre on the private fishery in 1969.

Hancock (1958) recorded densities of over 130 young starfish per square metre in the River Crouch in September 1955. However, by November it appeared that they had dispersed, leaving an average density of only 37 per square metre. Brun (1968) observed a column of _A. rubens_ passing over a bed of Icelandic scallops (_Chlamys islandica_). The column was 10m. wide and 100m. long and the density of starfish was 97 per square metre in the middle and 48 per square metre at the edge. All the above mentioned densities far exceed any starfish densities observed by the author at Clarinbridge or elsewhere on the west coast of Ireland.

Starfish generally occur on the public fishery only west of a line running south of Keave, a subjective estimate of their range being approximately 60% of the total area. Since the area of the fishery is 1,100,000 square metres the area infested with starfish is 660,000 square metres. On this basis the estimated starfish population on the public fishery in the latter half of 1971 was approximately 40,000.

Usually many starfish which are present on the oyster grounds at the beginning of December are removed by the fishermen during the first few days of fishing and by the end of the season the number of starfish being landed is negligible. Unfortunately, bad weather prevented a diving survey of the starfish population after the 1971 fishing season so it is not known how effective the month's dredging was in removing starfish or how quickly the fishery was recolonised.

Recolonisation of the oyster grounds may be achieved by the settlement of starfish larvae on the oyster grounds and/or by the immigration of adults from the west. The results of thorough searches of the fishery suggest that extensive settlement of larvae does not occur in the area. Furthermore, the generally larger size of the starfish on the public fishery indicated in Figure 31 suggests that immigration from the west is the main source of recruitment. However, Galstoff and Loosanoff (1939) who also observed a preponderance of large starfish near the head of a bay decided that an abundance of food caused faster growth in these starfish rather than ageing and growth during a period of migration. Whilst this reasoning may partly explain the annual recruitment of large starfish to the oyster fishery it is suggested that migration also plays a part.

It is known that the public fishery starfish population is continuous with the St. George fishery population along the channel to the south of Yellow Rocks. Furthermore, Hugh-Jones (1969) observed small starfish moving eastwards across the muddy area to the south of Ballynacourty pier from a 'nursery area' of small starfish (less than 30mm in radius), covering approximately one hectare at a density of 2.7 per square metre, off the north shore of Eddy Island. He pointed out that the rates of starfish movement noted by several authors (e.g., Medcof, 1961) would enable starfish settling in the 'nursery-area' mentioned above to reach the public fishery easily within three years.

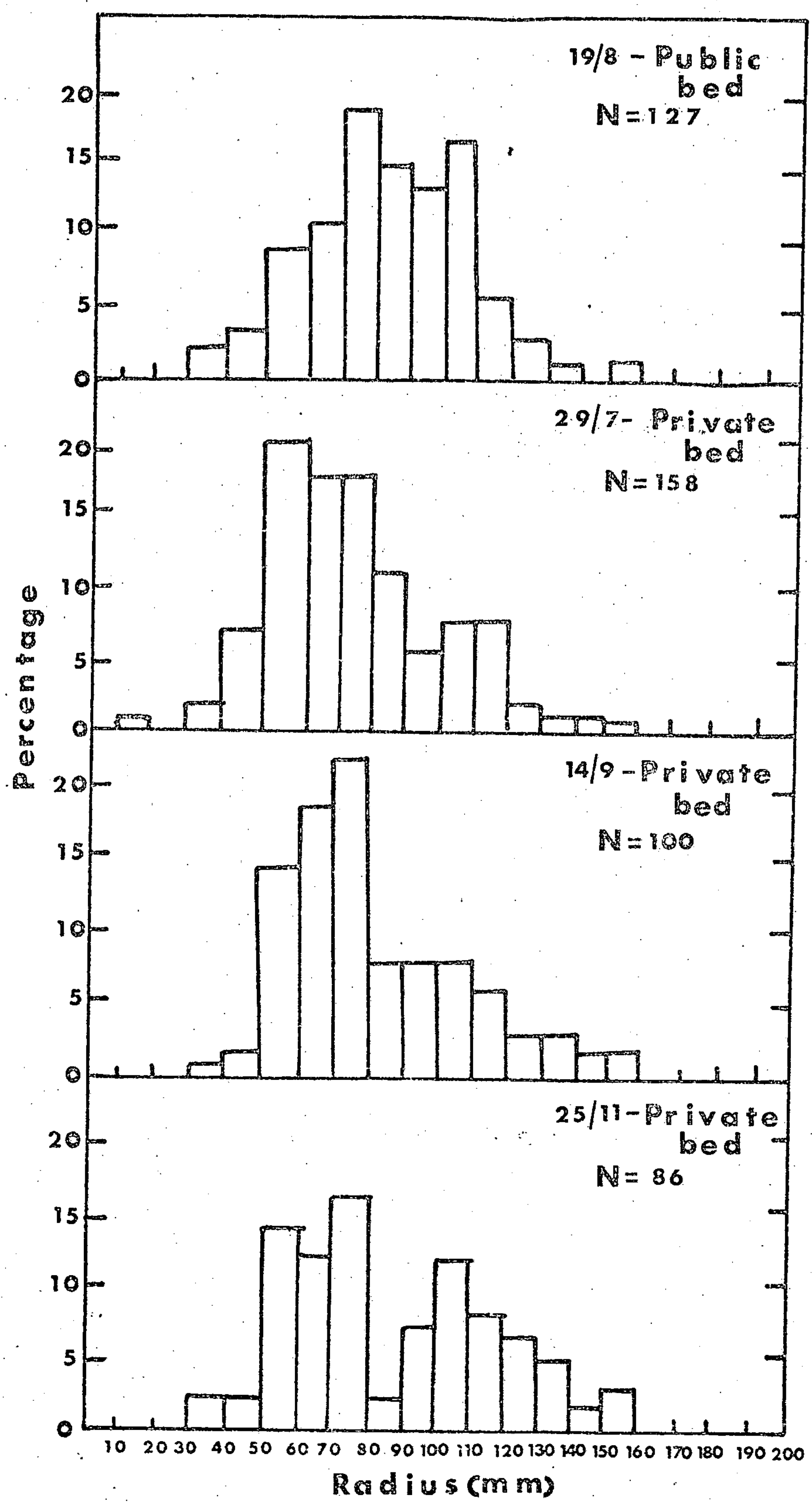
Finally, the decreasing densities of starfish radiating from the 'nursery' off Eddy Island, in conjunction with the larger size (see Figure 31) of starfish on the public fishery, suggests that migration is the major mode of dispersal in the area, other than the dispersal of larvae, which, according to Hancock (1956), tend to settle where adult starfish are already present.

(b) Food and Feeding

In the past considerable attention has been devoted to the study of starfish food and feeding behaviour in an attempt to assess the effects of these predators on oyster stocks. Most data have been collected by the analysis of stomach contents (Hunt, 1925), from the food held by starfish caught by dredging (Vevers, 1949) and by controlled laboratory experiment (Hancock, 1955). Each of these methods has serious limitations. With the first method it is often difficult to identify partially digested organisms and only a small proportion of the food consumed by a starfish is found in the gut because all but the smallest food items are digested externally. With the second method, it has often been found that by the time dredged starfish have reached the surface for examination they have released their prey, thereby giving a false impression of the food taken and proportion of starfish feeding. The drawback of the third method is that it does not generally take into account the influence of environmental factors or the effect of prey availability on food consumption. Thus, both Hancock (1955) and the author (Whilde, 1968) showed that starfish preferred mussels to oysters. However, since mussels are generally less available than oysters on British

FIGURE 31

THE PERCENTAGE FREQUENCY DISTRIBUTION OF STARFISH ON THE CLARINBRIDGE PUBLIC OYSTER FISHERY AND THE PRIVATE ST. GEORGE OYSTER FISHERY IN 1971.



and Irish grounds the observation is of limited practical importance.

In this study the food of starfish at Clarinbridge was determined by observing the animals directly with the aid of S.C.U.B.A. Furthermore, an attempt has been made to relate the food of the starfish with the food organisms present on the seabed.

Methods

In July 1971, a grid measuring 35m by 35m was staked out on the seabed with coloured P.V.C. coated cable at a site close to plankton sampling station IV (Map 6, Chapter IV) on the private St. George Oyster Fishery. The grid, which was located in approximately 6m of water at H.W.N.T., was divided into ten compartments 35m by 3.5m, the longer axis running N-S. Trial observations showed that a maximum of four compartments could be surveyed during one dive. Since there were generally more than 100 starfish in four compartments it was decided that one diving session would provide adequate samples for the food studies. The same compartments were surveyed on each occasion and it is assumed that the food consumed between observations in no way influenced the composition of the diet observed on subsequent occasions - i.e., that all food species were available in the same proportions throughout the study period.

The survey technique involved two divers swimming along the length of each compartment, one diver carefully collecting all the starfish and the organisms they appeared to be consuming while the other (the author) judged whether the starfish were actually feeding, measured the radius of the largest arem of each starfish, identified and measured (where possible) the prey. All starfish observed in the four compartments of the grid were measured and the results were recorded on a sheet of roughened plastic with a soft lead pencil.

Comparative information was collected from the public fishery using the same technique but without a grid, because the low density of starfish made the construction of a grid which would encompass an adequate number of starfish impracticable.

Information on the abundance of prey species was obtained by analysis of 100 grab samples (using the Baird grab mentioned in Chapter V) taken in an area adjacent to and of similar size to the grid on the private fishery and in an area of similar dimensions on the public fishery at the centre of the estuary to the south of Black Weir.

Results

Table 59 presents the numbers, densities and proportions of starfish feeding at various times during the latter half of 1971. The bottom water temperatures at each sampling date are also presented.

Table 59 indicates the frequency of occurrence of the organisms which the starfish were observed to be consuming on both the public and private fisheries.

Table 60 presents the size of individual starfish and the size of the organisms they were consuming.

TABLE 59

PROPORTIONS OF STARFISH OBSERVED FEEDING AT VARIOUS TIMES DURING 1971

Date	Location	Surface Water Temperature °C	Starfish N	Starfish Density (m^{-2})	No. Feeding	% Feeding
16/7/71	Private	16.9	300	---	45	15.0
29/7/71	Private	16.6	158	0.32	43	27.2
2/8/71	Public	17.6	108	---	25	23.0
17/8/71	Private	17.6	170	0.35	40	23.5
19/8/71	Public	17.6	127	---	24	18.9
8/9/71	Private	17.6	80	0.16	15	18.8
14/9/71	Private	16.6	100*	0.33	21	21.0
25/11/71	Private	7.8	86*	0.23	15	17.5

* 3 compartments of grid surveyed.

TABLE 60 FREQUENCY OF OCCURRENCE OF VARIOUS STARFISH FOOD ITEMS

Location	Public Oyster Fishery				Private St. George Oyster Fishery												Total			
Date	2/8/1971		19/8/1971		16/7/1971		29/7/1971		17/8/1971		8/9/1971		14/9/1971		25/11/1971		Public		Private	
Food Items	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Ostrea	15	53.6	15	62.5	2	4.4	7	16.3	4	10.0	2	13.3	2	9.6	--	--	30	57.7	17	9.5
Anomia	3	10.7	2	8.3	--	--	2	4.7	2	5.0	--	--	1	4.8	1	6.7	5	9.6	6	3.4
Tapes	--	--	--	--	--	--	--	--	2	5.0	--	--	1	4.8	--	--	--	--	3	1.7
Venus	--	--	--	--	11	24.4	4	9.3	2	5.0	3	20.0	--	--	1	6.7	--	--	21	11.7
Chlamys	1	3.6	--	--	--	--	3	7.0	3	7.5	--	--	--	--	--	--	1	1.9	6	3.4
Mytilus	2	7.1	2	8.3	--	--	1	2.3	1	2.5	--	--	1	4.8	--	--	4	7.7	3	1.7
Gibbula	--	--	--	--	5	11.2	5	11.6	3	7.5	--	--	1	4.8	--	--	--	--	14	7.8
Calliostoma	--	--	--	--	--	--	1	2.3	--	--	1	6.7	1	4.8	1	6.7	--	--	4	2.2
Buccinum	--	--	--	--	--	--	--	--	2	5.0	--	--	--	--	--	--	--	--	2	1.1
Carcinus	--	--	--	--	1	2.2	3	7.0	1	2.5	--	--	1	4.8	--	--	--	--	6	3.4
Lepidochitona	--	--	--	--	13	28.9	8	18.6	6	15.0	6	40.0	8	38.1	5	33.3	--	--	46	25.6
Pomatoceros	--	--	--	--	2	4.4	5	11.6	--	--	--	--	1	4.8	2	13.3	--	--	10	5.6
Balanus	7	25.0	5	20.9	10	22.3	4	9.3	14	35.0	3	20.0	4	19.1	5	33.3	12	23.1	40	22.3
Gari	--	--	--	--	1	2.2	--	--	--	--	--	--	--	--	--	--	--	--	1	0.6
No. Species	5		4		8		11		11		5		10		6		5		14	
Total No. Individual Items	28	100.0	24	100.0	45	100.0	43	100.0	40	100.0	15	100.0	21	100.0	15	100.0	52	100.0	179	100.0

TABLE 61

THE SIZE OF STARFISH AND THEIR FOOD ITEMS (mm)

29/7/1971 Pr.			2/8/1971 P.			17/8/1971 Pr.			19/8/1971 P.			8/9/1971 Pr.			25/11/1971 Pr.		
Starfish Radius	Food	Food Size [1]	SR	F	FS	SR	F	FS	SR	F	FS	SR	F	FS	SR	F	FS
55	*Ostrea*	15 [2]	100	*Ostrea*	40	52	*Ostrea*	8	53	*Ostrea*	40	82	*Ostrea*	20	75	*Venus*	42
55	"	15	130	"	67	93	"	6	80	"	40	42	"	20	72	*Anomia*	32
75	"	14	100	"	48	110	"	28	105	"	45	115	*Venus*	44			
60	"	20	93	"	14	60	"	40	85	"	30	96	"	45			
60	"	15	122	"	42	70	*Chlamys*	17	110	"	52	130	"	33			
66	"	14	120	"	25	152	"	42	72	"	32						
57	"	13	100	"	22	42	"	38	110	"	50						
57	*Anomia*	16	110	"	70	75	*Anomia*	35	108	"	68						
42	"	12	130	"	65	74	"	18	98	"	32						
62	*Mytilus*	20 [3]	112	"	28	133	*Tapes*	13	127	"	52						
90	*Venus*	34	85	"	28	82	"	18	74	"	38						
100	"	40	90	"	62	162	*Venus*	50	128	"	32						
77	"	40	110	"	50	132	"	45	95	"	47						
145	"	41	106	"	54	80	*Mytilus*	36	72	"	57						
70	*Gibbula*	13 [4]	85	"	38	53	*Gibbula*	11	104	"	32						
60	"	11	110	*Anomia*	35	82	"	14	115	*Anomia*	48						
70	"	9	100	"	32	68	"	10	62	"	22						
55	"	10	135	*Chlamys*	52	75	*Buccinum*	75 [5]	105	*Mytilus*	50						
74	*Calliostoma*	11	110	*Mytilus*	72	120	"	72	76	"	37						
			107	"	60												

Pr = Private Fishery
P = Public Fishery

1 = Measurable Items
2 = Maximum diameter (mm)
3 = Length (mm)
4 = Breadth (mm)
5 = Height (mm)

TABLE 62 RESULTS OF THE GRAB SURVEY ON THE PRIVATE ST. GEORGE OYSTER FISHERY

Species*	No.	%	% of Food					Density (m^2)	Size range (mm)	
			29/7	17/8	8/9	14/9	25/11		On bed	In Food
Ostrea	6	8.1	20.6	15.4	16.7	12.5	--	0.6	12-72	13-40
Anomia	10	13.5	5.9	7.7	--	6.3	12.5	1.0	9-42	12-35
Tapes	12	16.2	--	7.7	--	6.3	--	1.2	11-21	13-18
Venus	10	13.5	11.8	7.7	25.0	--	12.5	1.0	16-47	34-50
Chlamys	4	5.4	8.8	11.5	--	--	--	0.4	18-40	17-42
Mytilus	--	--	2.9	3.9	--	6.3	--	--	--	20
Gibbula	12	16.2	14.7	11.5	--	6.3	--	1.2	9-10	9-14
Calliostoma	2	2.7	2.9	--	8.3	6.3	12.5	0.2	11	11
Buccinum	2	2.7	--	7.7	--	--	--	0.2	73	72-75
Carcinus	8	10.8	8.8	3.9	--	6.3	--	0.8	--	
Lepidochitona	8	10.8	23.5	23.1	50.0	50.0	62.5	0.8	--	
Total	74	99.9	99.9	100.1	100.0	100.3	100.0	7.4		

*Excluding *Balanus* and *Pomatoceros*

TABLE 63 RESULTS OF THE GRAB SURVEY ON THE CLARINBRIDGE PUBLIC OYSTER FISHERY

Species*	Number	%	% of Food		Density ($/m^2$)	Size range (mm)	
			2/8/1971	19/8/1971		On Bed	In Food
Ostrea	73	73.0	71.4	79.0	7.3	10-94	14-70
Anomia	13	13.0	14.3	10.5	1.3	14-59	32-40
Tapes	3	3.0	--	--	0.3	26-34	--
Venus	1	1.0	--	--	0.1	47	--
Chlamys	6	6.0	4.8	--	0.6	15-57	57
Mytilus	--	--	9.5	10.5	--	--	60-72
Gibbula	--	--	--	--	--	--	--
Calliostoma	--	--	--	--	--	--	--
Buccinum	--	--	--	--	--	--	--
Carcinus	4	4.0	--	--	0.4	--	--
Lepidochitona		--	--	--	--	--	--
Total	100	100.0	100.0	100.0	10.0		

*Excluding *Balanus* and *Pomatoceros*

Tables 62 and 63 present the proportion of known food items (i.e., those which starfish were observed consuming) recorded in the grab surveys and the frequency of occurrence of the food items being consumed by starfish during each survey. Also presented are the densities of the organisms on the sea-bed and the size ranges of the various species on the seabed and in the food. Barnacles (Balanus balanoides) and the tube worms (Pomatoceros triqueter) are omitted from these tables as it was found impossible to assess their numbers or availability to a starfish in the time available.

Table 64 presents the relationship between the size-frequency distribution of starfish and their oyster prey on the two fisheries.

Discussion

Table 59 shows that the mean number of starfish observed feeding at any one time was approximately 21% on both fisheries. This figure compares closely with observations made by Hugh-Jones (1969) on the St. George Fishery. He noticed that out of 831 starfish observed in three diving sessions in September 1969, almost 25% were feeding.

It will be noted that the proportion of starfish feeding in November 1971, when the bottom water temperature was 7.8°C, was well within summer values. This confirms Hancock's (1955) tank observations that starfish continue feeding through winter. He found that feeding ceased only when the temperature dropped to approximately 2°C . Since such low temperatures rarely occur at Clarinbridge it can be assumed that starfish continue to feed throughout the year, except around spawning-time (May-June) when feeding usually ceases for a short time (Hancock, 1955).

Table 60, which illustrates the frequency of occurrence of various food species in the starfish diet, shows clearly that oysters make up a large part of the diet of starfish on the public bed, but are ranked only fourth on the St. George fishery. However, reference to Tables 62 and 63 (which exclude tube-worms and barnacles which form a large part of the starfish diet) indicates that the proportion of oysters in the public fishery fauna is similar to that observed in the starfish diet, whilst the proportion of oysters in the St. George fishery fauna is considerably less that the proportion observed in the starfish diet. Thus, although the numbers of oysters are small on the St. George fishery the starfish appear to consume slightly more, relative to the other species available, than they do on the public fishery.

TABLE 64

SIZE FREQUENCY DISTRIBUTION OF STARFISH AND OYSTERS CONSUMED BY THEM

Size Class (mm)	Starfish Numbers		Oyster Numbers	
	St. George	Public	St. George	Public
1-10	--	--	2	--
11-20	--	--	9	1
21-30	--	--	1	5
31-40	--	--	1	9
41-50	1	--	--	6
51-60	7	1	--	4
61-70	1	--	--	5
71-80	1	4	--	--
81-90	1	4	--	--
91-100	1	6	--	--
101-110	1	8	--	--
111-120	--	2	--	--
121-130	--	5	--	--

Table 65 below presents a list of food items observed by Hugh-Jones (1969) on the private fishery.

TABLE 65

THE COMPOSITION OF STARFISH FOOD ON THE ST. GEORGE OYSTER FISHERY IN 1969

Species	%
Ostrea	15.0
Anomia	22.0
Tapes	--
Venus	6.5
Chlamys	1.0
Mytilus	2.5
Gibbula	44.5
Calliostoma	--
Buccinum	1.0
Carcinus	2.0
Lepidochitona	3.5
Pomatoceros	--
Barnacles	2.0

The table shows that oysters formed a similar proportion of the diet in 1969 as they did in 1972 (in spite of a decrease in the oyster population during the interim period). Anomia was a more prominent feature of the diet in 1969 as was Gibbula, which appears to have been a major item of the diet at the time of Hugh-Jones' survey. Venus appears to have been a regular item in the diet in both years. Barnacles and tube worms were only of minor importance in 1969 according to Hugh-Jones. However, this would seem unlikely since these species form an important part of the diet of small starfish, even when other species are available (Hancock, 1955). The low proportions noted by Hugh-Jones are probably due to his not noticing starfish eating barnacles. This is quite easy if every starfish is not examined closely because often they do not take on the characteristic hunched feeding position when eating such small organisms.

Chitons appear to have been a much more important component of the starfish diet in 1971 than in 1969. In fact, they were the commonest food item recorded in the 1971 survey.

The number of suitable food species on the public fishery appears to be quite low - 5, compared with 14 on the St. George fishery. Important food species which occurred on the private fishery, but which were absent from the diet of starfish on the public fishery, were Venus verrucosa, Lepidochitona cinereus and Gibbula sp. It is notable that barnacles made up a similar proportion of the diet of starfish on both fisheries. Generally they were eaten by smaller starfish, ranging in size from 40 to 80 mm radius (Table 66). Vevers (1949) also observed that barnacles were a major part of the diet of young starfish and Hancock (1955) showed that a changeover from a barnacle diet to one consisting of larger species came in the size range 70-100mm. Only occasionally were starfish larger than 100mm radius observed eating barnacles in Hancock's experiments or at Clarinbridge.

Chitons were eaten by starfish of all sizes, although the majority were taken by the smaller size groups (Table 65). The large proportion of chitons in the starfish diet suggests that these animals were under-represented in the grab survey. Chitons do not appear in the food lists presented by other authors who collected starfish by conventional means (Hunt, 1925; Vevers, 1949) and the author has never taken starfish feeding on chitons in a dredge. Thus it appears that an important food item may have been overlooked had it not been observed directly with the aid of S.C.U.B.A. by Hugh-Jones (1969) and the author.

TABLE 66

THE SIZE-FREQUENCY DISTRIBUTION OF STARFISH FEEDING ON BARNACLES AND CHITONS ON THE ST. GEORGE OYSTER FISHERY IN 1971.

Radius (mm)	No. of Starfish feeding on:	
	Barnacles	Chitons
41-50	5	2
51-60	9	4
61-70	9	3
71-80	7	4
81-90	1	-
91-100	1	2
101-110	-	2
121-130	-	-
131-140	-	1

Hunt (1925) and Vevers (1949) mentioned worms as part of the starfish diet. No starfish were observed eating worms at Clarinbridge by Hugh-Jones (1969) or by the author. Hunt (1925) also noted *Turitella* (tower shells) in his list of starfish food items. This species did not form part of the diet of starfish on either of the oyster fisheries but appeared to be an important component of the diet of starfish in Ballynacourty 'bay'. Here, starfish were observed consuming *Turitella* amongst a 'graveyard' of dead tower shells, which had been characteristically broken in half by *Asterias*.

Reference to Table 61 will indicate the general size relationship between starfish and their measurable prey (i.e., lamellibranchs and gastropods). The table shows clearly the absence of large oysters on the St. George fishery and there is a slight indication that saddle oysters (Anomia) were smaller on the private fishery than on the public fishery (see also the size range for these species presented in Tables 62 and 63).

Table 64 illustrates the general relationship between the size of starfish and the size of their oyster prey. It indicates that the small oysters present on the private fishery were generally eaten only by small starfish, while on the public fishery only larger oysters were taken by medium to large starfish.

Medcof (1961) repeated Needler's observation (Needler, 1941) that a starfish (A. vulgaris in this case) must have a diameter $1\frac{1}{2}$ times the diameter of its oyster prey if it is to attack it successfully. At Clarinbridge, the minimum starfish diameter to oyster diameter ratio observed was 2.7:1 and the exceptional maximum was 31:1 -- when a 186mm diameter starfish uncharacteristically consumed a 6mm oyster. If the smaller ratio (2.7:1) mentioned above was the minimum generally required to carry out a successful attack even the largest oysters at Clarinbridge (approximately 100mm in diameter) would be vulnerable to attack by the larger starfish.

c. Relaying Oysters on the St. George Oyster Fishery

On 17th July 1971, 200 oysters (size-frequency distribution given in Table 67) from the public fishery were distributed evenly over one compartment of the survey grid at a density of approximately 1.6 per square meter (the compartment was previously devoid of oysters). There were 20 starfish of various sizes in the compartment at the time. It was not possible to examine the oysters again until 7th September (21 days later) when 145 clocks (empty hinged shells) and 2 live oysters were recovered by diving. Each of the clocks showed typical signs of starfish predation (broken shell margins). The oysters which were not recovered were mainly of the smaller size classes and could easily have been hidden on the seabed or washed out of the compartment. It is suspected that the majority of these were also eaten by starfish.

At the end of the experiment there were 21 starfish in the compartment. However, it is not known whether the compartment was invaded by a large number of starfish which dispersed after consuming the oysters or whether the 20 or so starfish in the area had killed the oysters. If the latter was the case the feeding rate (assuming 197 oysters were killed) would have been 3.3 oysters per starfish per week. This rate of consumption is generally higher than that recorded by Hancock (1955) or Hugh-Jones (1969) in their feeding experiments. However, Hancock pointed out that starfish generally took less than two days to consume an oyster, which means that the sonsumption rate of 3.3 per week is just within this limit and might possibly have been achieved since the concentration of oysters in the compartment probably ensured a minimal time lapse between a starfish finishing one oyster and attacking another.

Table 67 presents the percentage size frequency of the oysters used in the experiment just described and also the size frequency distribution of the starfish in 4 lanes of the grid at the time. If it is assumed that a Clarinbridge starfish must have a diameter 2.7 times that of an oyster in order to prosecute a successful attack then the proportion of the starfish population which can successfully attack a given size class of oysters can be determined. If it is assumed that the size-frequency distribution of the starfish which consumed the relaid oysters was the same as that of the general population then the figures in column C of Table 67 represent the proportions of the starfish population in each size class which could have successfully attacked the relaid oysters. Thus, only 32.5% of the starfish population could have consumed oysters greater than 61mm in diameter (=19% of oysters) whereas 64.3% would have been capable of successfully attacking oysters greater than 51mm in diameter (=55% of oysters). On this basis it would be necessary to remove 64.3% of the (largest) starfish to save 55% of the (largest) oysters. If the starfish size to oyster size ratio was only 1.5:1 as noted by Needler, it would be necessary to remove considerably more starfish to ensure the survival of the same proportion of oysters.

<u>Asterias rubens and Hyas araneus</u>

Hancock (1955) states that <u>Asterias rubens</u> tends to be associated with the spider crab <u>Hyas araneus</u>. In his tank experiments he observed that "<u>Asterias</u> was frequently attacked by <u>Hyas</u> which injures the arms by constricting them with its chelae and biting the tips with its mandibles". This he attributed to the impatience of the crab while waiting for scraps

TABLE 67

DETAILS OF THE 1971 STARFISH/OYSTERS FEEDING EXPERIMENT

Size Class	Percentage Size Frequency Distribution		C
	Oysters	Starfish	
1-10	0	0	
11-20	0	0	
21-30	3.0	0	100.0
31-40	12.0	1.2	98.8
41-50	30.0	2.9	80.1
51-60	36.0	15.8	64.3
61-70	16.5	15.8	32.5
71-80	1.5	20.6	28.4
81-90	1.0	11.2	22.5
91-100	0	4.1	16.0
101-110	0	5.9	
111-120	0	6.5	
121-130	0	2.4	
131-140	0	10.0	
141-150	0	1.8	
151-160	0	1.2	
161-170	0	0.5	

to be dropped by the starfish. The author observed the same behaviour on the St. George fishery and on one occasion (17/8/1971) almost 30% of the starfish observed had lost one or more arms. This suggests more than 'impatience' on the part of the spider crab and it would appear to be a case of genuine predation since spider crabs were subsequently observed to devour entire starfish, as also were hermit crabs (Eupagurus bernhardus). Hancock (1969b), came to a similar conclusion in a later paper when he noted that Hyas fed on Asterias and that when it was taken in dredges it should always be returned to the seabed to help in the control of starfish.

2. Shore Crabs (*Carcinus maenas L.*)

Shore crabs are ubiquitous on the Clarinbridge Public Oyster Fishery. No attempt was made to estimate their numbers or their effects on the oyster stocks. The only definite evidence of crab damage at Clarinbridge was to spat on tiles which were held in crates at the centre of the fishery. The dead spat (which accounted for only a small proportion of the total number) had broken shell margins, consistent with crab damage observed in laboratory tests.

Hugman (pers. comm.) reported considerable crab damage to oysters held intertidally in Aughinish Bay in the spring of 1972. This he attributed, indirectly, to periwinkle spat (Littorina Littorea which crawled between the valves of feeding oysters which were then unable to shut, thus allowing small crabs to enter the oysters and feed. Since oysters at Clarinbridge do not generally occur in the periwinkle zone the possibility of large scale oyster mortalities of this nature is unlikely.

3. Tingles (*Ocenebra erinacea L.*)

Tingles, which bore holes in oyster shells and eat out the flesh, are rare on the Clarinbridge Public Oyster Fishery. Between February 1970 and July 1972 only 15 tingles were recorded on or near the fishery. These occurred mainly in the intertidal zone near Black Weir pier. No bored oyster shells were recorded on the fishery.

However, tingles do occur in small numbers in the

St. George fishery and a number of bored spat were recorded. Tingles are common in Aughinish Bay on the south coast of Galway Bay and cause considerable damage to spat (Hugman, pers. comm.). The author also recorded them in moderate numbers on oyster beds at Ardfry and in Kilkieran Bay (Map 3, Chapter II).

4. Oyster Catchers (*Haematopus ostralegus* L.)

Oyster-catchers were only observed to damage oysters which had been relaid intertidally by oyster dealers. Since most oysters at Clarinbridge occur below low water mark the threat presented by oyster catchers is negligible.

Competitors

A variety of organisms compete with oysters for settling space and food. The species which compete for settling space were dealt with in Chapter IV.

Presumably adult oysters compete with other species mainly for food. However, few conclusive data are available on this point and it was not possible to collect information on this important subject during the present study. However, observations on the fauna of the Clarinbridge oyster grounds suggest that potential competitors such as sea-squirts, saddle oysters, clams, fan worms and mussels do not occur in great numbers or at great densities and, therefore, do not present a serious threat to oysters unless the food supply is limited. The latter point will be considered again in Chapter VII.

Organisms Which Attack the Shell

The major organisms which attack oyster shells at Clarinbridge are the boring polychaete Polydora ciliata and the boring sponge Cliona celata. Dutch shell disease, which caused serious damage in Holland in the 1930's (Korringa, 1951) is not present at Clarinbridge but it is reported (Duggan, pers. comm.) to be present in Clew Bay in County Mayo where it has survived in old shells of oysters and other species.

Polydora

Both Polydora ciliata and Polydora hoplura were recorded in the shells of Clarinbridge oysters. They were identified indirectly by the form and position of the tunnels and mud blisters which they produced in the shells. However, no attempt was made to quantify the infestation rates of either species, but casual observations made throughout the study period suggest that the rate is relatively low and, on the basis of Korringa's (1952) observation that "oysters, especially when they contained over 25 Polydora ciliata, showed poor growth and were often leaner than non-infested oysters," it is unlikely that the observed infestations would affect the normal functioning of the majority of the oyster population. Generally, the maximum number of tunnels or blisters observed in any one valve did not exceed 5 and a large proportion of the oysters examined were free from internal infestations of Polydora.

Cliona celata

Cliona celata, which is recognised by the presence of yellow pustules of sponge on the outside surface of the shell, was present in only a small proportion of oysters examined during the study period. It was observed to be more prevalent in old dead oyster shells, many of which were honeycombed by the network of tunnels created by the sponge.

Parasites

In the present study no attempt was made to determine the existence of parasites in Clarinbridge oysters. However, Murray, who studied the distribution of the parasitic copepod, *Mytilicola intestinalis* Steuer, in mussels (*Mytilus edulis* L) in Galway Bay (Murray, 1971) examined oysters at Clarinbridge for this parasite. In spite of the relatively high infection of mussels in the area he found no *M. intenstinalis* in any of the 50 oysters he examined (Murray, pers. comm.).

It would appear that oysters are only liable to become heavily infested with *Mytilicola* when there are large quantities of larval parasites present and few mussels nearby (Hepper, 1956). If such a situation occurred the main danger would not be to oysters, but possibly to uninfected mussels in areas to which the infected oysters were transplanted. Thus, had Clarinbridge oysters been infected with *Mytilicola* it would have been unwise to carry out the growth experiment in Carlingford Lough described in Chapter V (Whilde, 1971) because the Lough supports an important mussel fishery which is free from *Mytilicola* (Parsons, pers. comm.)

The author found no evidence at Clarinbridge of the minute parasitic gastropod *Odostomia* sp. described by Cole and Hancock (1955). Although this parasite can cause some irritation to oysters it is found infrequently and, as yet, demands no special attention or control measures.

Disease

No large oyster mortalities, which could be attributed to disease organisms, have been reported from the Clarinbridge Oyster Fishery in recent years; nor have widespread mortalities been reported from any other Irish oyster fisheries since the epidemic of the 1920's which caused heavy mortality in Ireland and in other European oyster producing areas.

Environmental Factors.

Changes in a variety of environmental factors could seriously affect oyster production at Clarinbridge.

1. Land Drainage

The proposed acceleration of land drainage in the Dunkellin River catchment area (Connacht Tribune, 3/9/1971) could increase the flow of silt-laden freshwater over the Clarinbridge oyster grounds. This could lead to an increased deposition of silt on the oyster grounds and the smothering of large numbers of oysters, particularly spat.

An increase in the discharge of freshwater could be detrimental to the stocks at the eastern end of the oyster grounds where salinity is not always adequate for oysters at the present time. Furthermore, a reduction in the salinity of the surface waters in particular could have a deleterious effect on the oysters stored on intertidal layings by local oyster dealers.

Pollution

As stated in Chapter III the Clarinbridge Public Oyster Fishery is currently free from any serious form of pollution and the Kilcolgan River which discharges into the estuary is in a satisfactory condition (Flanagan and Toner, 1972). However, industrial development and the increase in population in the vicinity of Galway Bay pose a considerable long-term threat to the fishery.

1. Industrial Pollution

Industrial pollution is not a serious threat to Galway Bay at the present time. However, industrial development in the Galway region poses a long-term threat to the shellfish fisheries in the area. Several new industries in Galway wish to discharge heavy metals and toxic substances into the Galway sewage system (currently under construction) but they are being subjected to stringent regulations drawn up by the Galway Health authorities (Power, pers. comm.). It may be possible to enforce these regulations at the present time, but there is a danger that the industrial development will advance quicker than the control measures necessary to ensure safe effluents because of a lack of finance and manpower to undertake the fundamental research required for the formulation of the basic standards.

In February 1971, a sample of Clarinbridge oysters were analysed for heavy metal and organochlorines by the Dublin Public Analyst. The results, presented in Table 68 below, show that the concentration of heavy metals in the flesh of Clarinbridge oysters were fairly low and that pesticide residues were absent.

TABLE 68

THE CONCENTRATION OF VARIOUS METALS IN CLARINBRIDGE OYSTERS IN FEBRUARY, 1971

Element	Concentration (p.p.m. Dry Weight)
Zn	245
Cu	16
Pb	0.23
Ni	0.37
Cd	1.2
Hg	0.05
Cyanide	Absent
Organochlorines	Absent

At the present time no information is available to the author on the concentration of heavy metals in the waters of Galway Bay. Presumably they must be very low since the concentration in oysters, which are known to accumulate heavy metals, are also low.

Subsequent analyses for heavy metals, carried out as part of a quarterly survey conducted by the Galway Public Analyst in conjunction with the County Health Officer and the author, have shown little departure from the results presented in Table 68 (O'Donovan, pers. comm.). No increased concentrations have been noted but Cadmium has decreased to approximately

0.5ppm and Nickel has dropped to less than 0.1ppm. Oysters from Clarinbridge, Oranmore Bay and Aughinish Bay all contain similar, satisfactory levels of heavy metals.

2. Domestic Pollution

At the present time most of Galway's raw sewage passes directly into Galway Bay. This situation will continue until a new sewage system (currently under construction) is completed. This will discharge screened and macerated effluent into the Bay at a point to the southwest of the Docks at a depth of 30ft (Power, pers. comm.). The efficacy of the system leaves doubt in the author's mind, particularly as no detailed studies were made of the effects of currents and wind on the dispersal of the effluent in relation to the Oranmore Bay and Clarinbridge oyster fisheries. Apparently, however, provisions have been made for the construction of a full sewage treatment plant if the system under construction proves unsatisfactory in the long term (Power, pers. comm.).

Little raw sewage reaches the Clarinbridge estuary because the population in the vicinity is small and widely dispersed. Furthermore, B.O.D. measurements in the Kilcolgan River (Flanagan and Toner, 1972) indicates that the river is relatively free from organic pollution and, therefore, unlikely to have any harmful effect on the Clarinbridge estuary.

Bacteriological tests, carried out as part of the quarterly survey mentioned earlier, have shown that oysters at Clarinbridge, Oranmore Bay and Aughinish Bay have consistently contained less than one _Escherishia coli_ per millilitre of flesh (Grade I - provisional grading, Sherwood and Scott Thomson, 1953) indicating that they are satisfactory for human consumption without prior artificial purification.

The danger of bacteriological contamination of shell-fish and of oysters in particular may increase as the population of Galway and Oranmore increases. The summer periods may be particularly dangerous when the native population is increased by an influx of tourists. As Wood (1965, cited by Wood, 1969) pointed out, *Ostrea edulis* can concentrate up to six times the quantity of faecal bacteria present in the surrounding water at 16°C. Thus, the level of contamination at the beginning of the oyster season (September 1st) may require careful monitoring.

3. Agricultural Pollution

At the present time the discharge of agricultural chemical (fertilizers, pesticides, etc.) into Galway Bay is limited and presents no threat to fisheries in the area. However, the drainage of large areas in the Dunkellin River catchment area to increase and improve agricultural land in the district will, no doubt, be accompanied by an increase in use of fertilizers and other agricultural chemicals, which will eventually find their way into the river and then into the Clarinbridge estuary. While moderate eutrophication may help to improve the fishery the situation must be carefully monitored.

CHAPTER VII

IMPLICATIONS FOR MANAGEMENT

VII. IMPLICATIONS FOR MANAGEMENT

The purposes of this chapter are: (a) to assess the significance of the information presented in the foregoing chapters in the future conservation, management, and development of the Clarinbridge Public Oyster Fishery; (b) to outline some of the means by which the proposed improvements may be achieved; and (c) to discuss the problems facing the development of the fishery and to evaluate the effects of the changing state of the Irish and European oyster industries on the future of the Clarinbridge fishery.

(a) The Significance of the Environmental and Biological Factors in the Conservation, Management, and Development of the Clarinbridge Public Oyster Fishery.

1. Conservation

The Clarinbridge oyster population is one of the few remaining wild oyster populations in Europe and it is essential that it should be conserved, not only because of its commercial value but also because of the need to retain a genetically diverse reservoir of wild oysters to buffer any adverse effects of selective mass breeding of oysters in hatcheries, which may come to dominate the European oyster industry in the future.

On the basis of the information presented in the foregoing chapters it appears that the environmental and biological conditions at Clarinbridge are generally satisfactory for the for the perpetuation of the oyster stocks. Provided that the stocks are adequately protected and maintained there will be no problem in conserving them in the prevailing conditions.

However, if conditions deteriorate, exploitation and development may become uneconomic and it may become necessary to introduce special long-term conservation measures to ensure that the stocks are maintained at an adequate level.

2. Management and Development

The results presented in earlier chapters suggest that while conditions are adequate for the maintenance of the stocks they are not ideal for the levels of reproduction and growth required for modern intensive oyster cultivation.

1. Larvae Production and Spat Settlement

The particular factors influencing the level of larvae production and spat settlement at Clarinbridge could not be discerned percisely from the results of the investigations described earlier. Larvae production was poor even when water temperature and salinity appeared to be satisfactory during the breeding season. This suggests that conditions during the period leading up to the breeding season may influence the level of larvae production. For example, in 1971, when larvae production and spat settlement were very poor, there was less heat, less sunshine and less rainfall during the period prior to the breeding season than in the equivalent periods in 1968, 1969, or 1970 (Tables 28a, b and c, Chapter IV). This suggests, indirectly, that there may have been a lack of suitable food available during the crucial periods of gonad development and larvae release, possibly as a result of the low discharge of nutrient rich freshwater into the Clarinbridge estuary and lack of heat and sunshine to promote phytoplankton production. The relatively poor growth rate of Clarinbridge oysters in 1971, demonstrated in Chapter V, tends to reinforce this hypothesis.

ii Food

Very little is known about the food of oysters in natural conditions, or about the nutritional quality of various waters which support oysters of differing reproductive capacities, growth rates and quality. Waugh (1957b) stated that, "it appears that failure of the nannoplankton crop at the critical period when larvae are most abundant in the water results in their failing to grow. The converse normally applies; abundant nannoplankton results in good larval growth." However, he also pointed out that the right species of nannoplankton must be available at the right time and that a bloom of unsuitable or toxic species will result in poor larval growth and spat settlement. It may be speculated, therefore, that the poor growth and settlement of the few larvae produced in 1971 was attributable to the general lack of food or to the absence of suitable species at the crucial time. Such speculation tends to be reinforced by recent surveys conducted by members of the Department of Oceanography, University College, Galway, which revealed a general paucity of zooplankton in Galway Bay, in comparison with areas of a similar nature abroad (McKBary, pers. comm.).

As regards the natural food of adult oysters, Savage(1925), who carried out one of the few extensive investigations into the food of adult oysters, found that there was a difference in the quantity and quality of organisms taken from oyster grounds where fattening was satisfactory and from those where it was poor. He suggested that growth is due mainly to inanimate food (detritus) and fattening to diatoms. Since both growth and fattening were relatively poor at Clarinbridge during the study period both of these requirements (if Savage is correct) must have been in short supply for reasons which are as yet unknown.

If food is a regular limiting factor in the reproduction and growth of Clarinbridge oysters, as is suggested by the foregoing observations, it would appear that the basic requirements for the development of a profitable fishery may be lacking. Whether suitable food is present in adequate quantities at any time is not known. However, if the proposed shellfish farming developments on the west coast of Ireland are to succeed it will be necessary to investigate this problem and amend the plans according to the results obtained.

iii. Survival and Growth

The survival rate of any given size class of Clarinbridge oysters was found to be fairly similar to the rates recorded elsewhere (e.g., Walne, 1961). However, when viewed in conjunction with the slow growth rates recorded in Chapter V it will be noted that relatively fewer oysters can survive to a satisfactory commercial size than in areas where the growth rate is faster. Furthermore, the longer oysters take to reach commercial size the longer they are exposed to predation and adverse environmental conditions and the greater will be the effects on the stocks of poor spatfalls, such as occurred in 1971, because these 'blanks' will take longer to pass through the population.

iv. Population Structure

At the present time the Clarinbridge oyster population is dominated by oysters in the medium to large size classes (Figure 10, Chapter V) which settled in 1968 and 1969. A decline in the population in the mid 1970's is almost inevitable as a result of the poor spatfalls of 1970, 1971 and 1972 (Whilde, 1972). The main danger here is that the larger size classes will be removed by fishing, with the result that an inadequate breeding population of small oysters will be left to replenish the stocks. It will, therefore, be necessary to limit fishing during the next few years to ensure that sufficient large oysters (since these produce the most larvae) are retained to act as parent stock.

v. Pests

The Clarinbridge oyster grounds are relatively free from major oyster pests. Although starfish inflict minor damage to the stocks at the moment, they pose a considerable threat in the future, particularly if the starfish population on the adjacent St. George fishery is not reduced. The evidence presented in Chapter VI suggests that this population has 'eaten out' its food resources and may be moving slowly towards the public fishery.

The relatively slow growth rate of Clarinbridge oysters, with the accompanying increased period of susceptibility to starfish predation, will necessitate the regular clearance of starfish from the public oyster fishery and the introduction of measures to prevent the starfish from migrating on to the grounds.

vi Pollution

The present level of pollution in Galway Bay poses no immediate threat to the Clarinbridge oyster fishery. However, as noted previously, industrial and urban centres are being extended along the north and east shores of the Bay. Generally, these new developments are subjected to stringent anti-pollution regulations (Power, pers. comm.), but there are no built-in safeguards or deterrents against 'accidental' discharges of noxious or toxic effluents, which have been occurring with increasing frequency in recent times. The maximum fine for discharging toxic waste into a river or estuary in Galway is £5 - a penalty dating back to the latter years of the nineteenth century. Therefore, until anti-pollution legislation in Galway is updated it will be difficult to ensure the cleanliness of its water resources.

Although Galway Bay oysters are free from serious bacterial pollution, recent research (Smith, 1972, and pers. comm.) has shown that faecal coliform bacteria originating from Galway sewage effluent live longer in the sea than was formerly suggested, thereby giving them a greater dispersal time and a better chance of reaching the oyster beds in Oranmore Bay and at Ardfry in particular. Furthermore, a large proportion of the bacteria encountered have been shown to be resistant to six of the main antibiotics used in the Galway area, thus giving rise to the potential difficulty of treating persons infected with these bacteria either directly, by swallowing sea water or, indirectly, by eating infected shellfish.

vii Climate

The prevailing climatic conditions on the west coast of Ireland are adequate for the natural regeneration of the indigenous oyster stocks. Howevever, the results of the present study suggest that Galway Bay is only marginally suitable for intensive oyster cultivation in the current economic state of the European oyster industry because of the comparatively poor breeding success and slow growth rates referred to earlier. If the climate of the British Isles cools slightly during the latter years of the century, as has been the tendency in past centuries (Lamb, 1965), oyster production may well be forced into decline, largely through the inadequacy of summer temperatures for breeding. The effects of such a climatic deterioration can be predicted from the events which occurred in the summer of 1972 (Whilde, 1972). Surface water temperatures at Clarinbridge were, in general, $2^{o}C$ lower than recorded during the same periods in 1968 to 1971, as a result of unusually cold conditions in the Atlantic. The onset of larvae release was delayed by nearly one month and peak releases occurred only over a period of seven days at the end of August when the water temperature rose above $17^{o}C$. A small spatfall occurred at this time, but the subsequent drop in water temperature lead to poor spat growth which will limit the chances of their survival to the next growing season.

If similar conditions recur regularly over the next two or three decades the economic viability of the Clarinbridge oyster fishery may be seriously threatened.

b. Cultivation Techniques Currently Employed at the Clarinbridge Public Oyster Fishery and Suggestions for Their Improvement

The development of the Clarinbridge Public Oyster Fishery, like that of any publicly owned natural resource, has been severely limited by the absence of a positive management policy and the lack of effort and cooperation on the part of those concerned with the exploitation and upkeep of the fishery (Whilde, in press,c). In the past the local fishermen supervised the fishery themselves and from time to time distributed clean shells over the oyster grounds to increase oyster spat settlement. However, it appears that there was never a concerted effort to manage the fishery in such a way as to obtain a sustained or increased yield.

In 1967, however, the B.I.M. Resource Development Section, in cooperation with the reconstituted Clarinbridge Oyster Development Committee and the Fisheries Division of the Department of Agriculture and Fisheries, initiated a programme of research and development. The development work, which was carried out mainly by members of the Clarinbridge Oyster Development Committee and supervised by the author, involved the distribution of a variety of spat collectors prior to spatfall, the harrowing of the oyster grounds to release silt and weed and to expose clean surfaces for spat settlement and the removal of starfish.

1. Spat Collection

i. Mussel Shells

Observations described in Chapter IV indicated that up to 20% of the single mussel shells distributed loosely over the oyster grounds caught spat during their first season. If a conservative overall estimate of the number of single mussel shells catching spat in the years 1968 - 1971 is taken as 10% and it is assumed that the average number of single shells per metric ton is 120,000 (a figure based on results presented in Chapter IV) then one metric ton of shells caught 12,000 spat in their first season. If 1% of these spat survive to a good marketable size (Chapter V) then one metric ton of mussel shells will yield 120 commercial oysters (almost one long hundred) worth £3 to £4 at current market prices.

In Table 69 the approximate cost of carriage (the shell was given free to the Committee by the mussel processors), handling and distribution of one metric tone of mussel shells in 1971 is compared with the predicted return in the form of commercial oysters in 1976 or 1977.

On the basis of these calculations the distribution of mussel shells is uneconomic in the long term. However, it is known that the shells also catch spat in their second and third years on the oyster grounds and that larvae also settle on the first settled spat. Therefore, it can be assumed that, even with the low intensity of settlement recorded in 1971, the differential between the cost price and the return will be less than indicated in Table 69, particularly if the price of oysters is higher in 1976 than at present.

TABLE 69

THE ECONOMICS OF MUSSEL SHELLS AS SPAT COLLECTORS

	Cost (£) 1971	Return (£) 1976 or 1977
Carriage of 1 mt.	5	
Bags (1)	1 (2)	
Bagging	3 (2)	
Distribution	6 (2)	
Total	£15	£3 to £4

(1) - Each bag used several times
(2) - Courtesy of the Clarinbridge Oyster Development Committee.

Thus, even if the distribution of mussel shells appears to be uneconomic in some years it may ultimately provide direct economic benefit to the fishery as well as indirect benefit in the form of seabed improvement. Finally, it must be noted that the distribution of mussel shells tends to give the fishermen a psychological boost when they see that improvements are being undertaken on their behalf.

Improvement of Spat Catching Efficiency

The spat catching efficiency of mussel shells can be improved in a number of ways:

(1) by ensuring that the ground on which the shells are distributed is firm, clean and free from obstacles (rocks and seaweed) which will prevent larvae settling on the shells;

(2) by ensuring that the shells are not distributed too early because of the danger of excessive fouling which would render them useless as spat collectors;

(3) by ensuring that the shells are distributed singly. Hinged shells often shut and fill up with silt which renders them unsuitable for spat settlement;

(4) by ensuring that shells are distributed evenly over selected areas of the oyster grounds, not in heaps.

Generally mussel shells held in mesh bags caught fewer spat than mussel shells distributed loosely (Chapter IV). However, they could be recovered more easily and those with spat attached could be selected and transferred to the next stage of the cultivation programme while the remainder could be retained for use during the next season. Such a practise on a large scale, however, would be costly, particularly in terms of labour,and would probably be economic only in years of heavy spat settlement.

ii Tiles

In Chapter VI it was shown that limed tiles were particularly effective spat collectors. They were relatively cheap to purchase and prepare (approximately £35 per 1,000) but they were difficult to distribute and to transplant prior to the fishing season. Furthermore, since Clarinbridge spat require at least 18 months to reach a size at which they can be safely detached from the tiles it would be necessary to employ at least two sets of tiles over alternate years. Finally, the cost of labour needed to detach spat would probably render the use of tiles uneconomic in the present state of the fishery.

iii Cardboard Egg Trays

These collectors were found to be relatively cheap and easy to prepare (Chapter IV) and unlike the tiles they were easy to handle and distribute. They had a high catching rate (e.g., in 1968) because of their large surface areas and had the added advantage, when correctly prepared, of decomposing naturally after $1\frac{1}{2}$ to 2 years, leaving single spat.

It is not possible to present a realistic cost estimate for the preparation of the egg trays in 1971 because most of the work was carried out on a voluntary basis by members of the Clarinbridge Oyster Development Committee.

2. Harrowing the Oyster Grounds

In April and May 1972 the oyster grounds were harrowed, on ebbing tides, with a 6ft weighted scallop dredge frame in an attempt to release silt and expose clean shell surfaces prior to the breeding season. The operation was hampered by the tangling of large quantities of seaweed (mainly *Laminaria* spp.) in the dredge and no quantitative assessments of its effects could be made.

Sayce and Tufts (1967) carried out harrowing tests on Pacific oyster grounds in the United States. They found that harrowing had no effect on the condition of the oysters nor any effect on the mortality levels unless the harrowing was repeated several times. After ten harrowing sessions they observed high rates of mortality which they attributed directly (oysters broken) and indirectly (actual cause of mortality unknown) to the harrowing.

At Clarinbridge dredge surveys carried out after the harrowing revealed no broken oysters or any mortalities which could be attributed to harrowing. In fact the extensive nature of the harrowing operation probably had less effect on the oyster grounds and the oyster stocks than normal dredging operations carried out in December. Therefore, extensive harrowing cannot be advocated as a major cultivation practice. However, intensive harrowing would be valuable in the preparation of small specially selected areas of the oyster grounds (e.g., areas to be used for the relaying of newly detached spat).

3. Starfish Clearance

As mentioned in the previous chapter starfish clearance is now a regular by-product of the fishing season and a large proportion of the starfish present on the oyster grounds at the beginning of December are removed within a few days. However, starfish subsequently recolonise the grounds, but the relatively small numbers reported earlier probably do little serious damage to the oyster stocks at the present time.

However, these observations should not lead to complacency and low densities of starfish should be maintained by regular dredging or diving operations and the introduction of methods to prevent starfish reaching the oyster grounds.

c. Possible Changes in the Organisation of the Clarinbridge Public Oyster Fishery.

Major improvements in the management and cultivation techniques employed at Clarinbridge will be achieved only by a radical change in the organisation of the fishery. There are three levels of organisation through which the Clarinbridge fishery might be developed: 1. the current Clarinbridge Oyster Development Committee; 2. a fishing cooperative; 3. a fishing cooperative with a manager.

1. The Clarinbridge Oyster Development Committee

If the present system is retained, whereby a committee of fishermen and oyster buyers is elected annually to organise the fishery development work, an increase in oyster production at Clarinbridge is unlikely, for three reasons:

(i) The Committee receives only a small sum of money annually for the development of the fishery. This consists of a contribution from the proceeds of the annual Galway Oyster Festival (£200 in 1971) and any money that can be raised through local functions. This money scarcely covers the provision of mussel shells, let alone the use of more sophisticated cultivation techniques.

(ii) With the present system few fishermen are willing to contribute money or labour for the development of the fishery if others, who do not participate in the development work, are likely to benefit from their labour. This problem is further accentuated when landings are small and prices are low because the fishermen will not contribute to the development of the fishery if the rewards are likely to be small.

(iii) Because the fishery is relatively small and lasts only for one month no fishermen rely on oysters for their entire livelihood and, therefore, few feel any personal obligation to the development of the fishery.

Therefore, it must be concluded that if the current organisation is retained there will be little opportunity to develop the fishery. The level of commercial production will continue to depend entirely on the natural recruitment of spat and, therefore, fluctuate accordingly. The lack of quality control which accompanies this level of organisation will weaken the competitive position of Clarinbridge oysters in relation to the increasing numbers produced by the private sector. The value of Clarinbridge oysters will not rise as fast as that of privately grown oysters and eventually it may become uneconomic to fish at Clarinbridge.

2. A Fishing Cooperative

There is a danger that once the temporary E.E.C. inshore fishery protection regulations are revoked foreign fishermen may attempt to exploit the two major public oyster fisheries from bases outside Ireland. In an effort to offset this danger oyster fishing cooperatives have been established at Clarinbridge and Tralee Bay with a view to their gaining sole legal rights to the fisheries. At the time of writing the cooperatives were filing applications to the Minister of Agriculture and Fisheries for the granting of Fishery Orders (see Chapter II) which, if approved, will bring the fisheries under the private control of the cooperatives and automatically provide legal safeguards against exploitation by foreign fishermen.

Membership of the cooperatives is open to any person residing in Ireland and it will entitle him to participate in the fishery at the appointed time. However, it is anticipated that only fishermen and oyster buyers will join the cooperatives initially.

The granting of a Fishery Order at Clarinbridge, for example, could be prevented by a single objection if this is upheld by the Minister of Agriculture and Fisheries after the public inquiry arranged to examine the application in December 1972. It is known that certain local oyster buyers may object to the granting of the Fishing Order because they fear that this will adversely affect their own operations. However, this fear is quite unfounded because the cooperative will be purely a fishing organisation with no commercial function. Each fisherman will be free to sell his oysters as he wishes.

If the Clarinbridge cooperative is granted a Fishery Order it should be possible to improve the level of management and to initiate better cultivation techniques because: (1) each member of the cooperative will be obliged to pay an annual membership fee (not yet fixed, but likely to be between £1 and £10) which will go towards the upkeep and the development of the fishery. If all the fishermen currently participating in the fishery (well over 100) join the cooperative substantially more money will become available for the running of the fishery; and (2) each member of the cooperative will have a financial stake in the fishery and should, therefore, feel a greater personal responsibility towards the conservation and the management of the fishery.

3. A Fishery Cooperative With A Manager

While the granting of a Fishery Order to the cooperative may serve to protect the Clarinbridge fishery and indirectly provide more funds for its development it will not guarantee that the development will be performed effectively. Only the appointment of a fishery manager (and permanent staff) to carry out the day to day running of the fishery will ensure that the funds are put to the best use.

If the members of the cooperative eventually decide to appoint a manager there are indications that government grants will be made available to assist in the payment of the manager's salary during the initial period of his employment.

It will be the manager's responsibility to implement new cultivation techniques, improve quality control and eventually, perhaps, to develop and execute the marketing operations for the members of the cooperative. It will also be his duty to continue the monitoring of basic physical and biological factors which was initiated by the B.I.M. Resource Development Section.

c. Future Problems in the Development of the Clarinbridge Public Oyster Fishery.

1. Organisation

In the previous section the evolution of the fishery through three levels of organisation (including the current stage) was considered. The attainment of the second and third stages will depend on the action and determination of the local fishermen and the willingness of various government departments and semi-state bodies to support their current proposals. If the proposals are carried through to the extent that a manager is appointed then the following factors will require immediate attention.

2. Quality Control

Quality control must be placed high on the list of management priorities because only by marketing a high quality product will it be possible to establish strong markets abroad and to compete on equal terms with oysters produced by private Irish oyster fisheries. At the present time a large proportion of the oysters sent away from the Clarinbridge fishery are of poor or inconsistent quality. This is due to a lack of discrimination on the part of the fishermen and to the low standards of cleaning and grading by oyster buyers. It would be in the long-term interest of the cooperative, and the function of the manager, to ensure that only good quality oysters are taken from the fishery and that these are properly cleaned and graded before marketing.

The requisite qualities of good commercial oysters have been outlined by the author (Whilde, in press,c) and are summarised below.

The oysters should be:

(a) well shaped -- round and deep, 76mm to 100mm in diameter and 60g to 120g in weight;

(b) free from external fouling organisms and burrowing worms and sponges;

(c) moderately thick shelled;

and should have:

(d) clean, white internal shell surfaces with no chambering;

and (e) plump, creamish meat, free from dark blemishes, discoloured gills, peacrabs or worms.

These qualities can be attained by various cultivation techniques (e.g., regular dredging) and judicious selection and treatment by the oyster buyers.

3. Spat Production

A continuity of supply must be maintained by the annual recruitment of seed oysters into the stocks by spat collection at Clarinbridge and, when necessary (e.g., after a succession of poor spatfalls), by the importation of seed from hatcheries or from other approved sources (see later).

The methods of spat collection employed at Clarinbridge were discussed in an earlier section. It should be the function of the manager to utilise such methods and to develop new and more effective techniques when possible.

One material, P.V.C. sheeting, which proved unsuccessful in spat collection trials at Clarinbridge because of poor spatfall produced encouraging results at the Tralee Public Oyster Fishery (Duggan, pers. comm.) and should be considered for further large-scale trials because it is light, easy to handle, durable and when thin sheets are employed it is sufficiently flexible to allow small spat (ca 5mm) to be flicked off into trays.

4. Improvement of the Oyster Grounds

At the present time the Clarinbridge oyster grounds are densely covered with old decaying shells which: (1) are of no value as spat settlement surfaces; (2) harbour silt and pests such as the boring sponge (*Cliona*); and (3) make up an excessive proportion of the material dredged up by the fishermen. These should be systematically removed (ensuring that all attached oysters are returned to the seabed) and laid at the top of the shore to dry out. At a later date they can be used to harden up muddy areas at the periphery of the oyster grounds to extend the cultivable areas.

5. Increase in the Standing Crop

It will be the function of the manager to increase the standing stock of commercial oysters by systematically increasing their density on the grounds. The current standing stock of oysters is approximately 2mt/ha, of which 0.4mt/ha are of commercial size. This stocking rate could be increased considerably without detriment to the stocks in view of the high stocking rates already employed on private fisheries (e.g., 15 to 30mt/ha in France). Furthermore, Sheldon (1968) showed, in small scale experiments, that a stocking rate equivalent to 40mt/ha of small brood oysters (the author's estimate from Sheldon's results which were given in numbers per acre) could be maintained without increasing mortality rates or seriously depressing growth rates.

6. Zoning the Fishery

Ultimately it may be necessary to zone the fishery into a spat collecting zone, a growing-on zone and a fishing zone. In reality this may mean only two physical zones because the best spat collecting area and the most suitable fattening and fishing area is the western part of the oyster grounds, to the south of Black Weir pier. It is suggested that an area south of Keave should be utilised for growing-on spat (transferred from the collecting area prior to the fishing season), provided salinity conditions prove to be consistently adequate. Here the seabed is clean, starfish are absent, tidal currents are moderate and parts of the area uncover at low spring tides, thereby facilitating the installation and maintenance of racks or other structures selected for holding spat.

The spat should be held in well-protected trays or bags until they are sturdy enough to be relaid on specially prepared, unfished ground nearby. As they approach commercial size they should be transplanted onto the fishing grounds (e.g., in January) to fatten and to supplement the indigenous stocks. Only if a system such as this is developed economically will it be possible to utilise the artificially collected spat to their full advantage.

No realistic figures are available for the employment of tray cultivation techniques at Clarinbridge. However, Key (1969) analysed the effectiveness and cost of rearing small oysters (approximately 5 grams) in trays in Essex. He found that the oysters grew best at low densities (3.75Kg per square metre) but that it was economically more advantageous to hold the oysters at 7.5Kg per square metre because the current price for the greater numbers outbalanced the price paid for the smaller numbers of larger oysters. Holding oysters at 15Kg was rendered uneconomical by a decrease in mean weight and a higher mortality rate. Key (1969) also reported that the survival of oysters was greatest in the top tray of a stack and that the cost (including purchase price of oysters, trays, etc.) of each 1000 oysters recovered from these trays after 5 months was approximately £5. When it is considered that the growth rate of oysters on the west coast of Ireland is slower than in Essex and that the cost of materials is likely to be higher it is clear that the introduction of tray cultivation at any stage of the Clarinbridge development programme must be preceeded by careful cost benefit analysis.

7. Pest Control

It was pointed out earlier that starfish and crabs are the major pests on the Clarinbridge oyster grounds. The starfish, which are not present in serious concentrations at the moment, must be maintained at low densities by routine dredging or diving operations.

On the other hand, crab damage can be avoided only by the protection of small oysters afforded by artificial cultivation techniques such as tray or raft culture. However, these techniques are expensive and by no means foolproof. For example, Key (1970) noted a large number of crabs damaging and eating Norwegian O. edulis spat in experimental wire trays. In subsequent laboratory trials he found that the crabs (54mm to 60mm carapace width) ate, on average, one spat per day each. While crabs may not eat spat at such a high rate in natural conditions the results presented by Key are disturbing when the large numbers of crabs present in the Clarinbridge oyster grounds are considered.

It is very difficult to prevent crabs entering trays or cages except when very fine mesh (ca 5mm) casing is employed. However, the advantages of such fine mesh are usually soon lost as it rapidly becomes clogged with fouling organisms and silt, with the result that the circulation of water over the oysters is reduced, food supply is diminished and, ultimately, growth is checked.

Until it is possible to evaluate crab damage accurately and set the cost against the costs involved in developing and implementing protective measures it cannot be recommended that any special precautionary measures should be undertaken.

8. Fishing Controls

Any advances in the organisation of the Clarinbridge Fishery should bring an easing in the control of fishing activities. The basis for catch limits should be orientated towards quality rather than a minimum size. However, it would be difficult, even for a resident manager, to enforce such regulations while the fishermen are free to sell their oysters to whom they wish. If the cooperative eventually develops a marketing function it will be in the interest of the members (fishermen) to abide by quality control regulations.

It will be necessary to assess the size of the commercial stocks before each fishing season in order to set a quota which will ensure that sufficient adult stocks are allowed to remain for the following breeding season.

With the setting up of a cooperative it may be possible to extend the fishing season, or at least make its timing more flexible, so that the stocks can be fished during periods when the oysters are in their best condition. These periods vary from year to year (Chapter VI) and may be as early as October or as late as May, but generally they do not coincide with the present fishing season.

9. The Effect of the Expansion of the Private Sector on the Development of the Clarinbridge Public Oyster Fishery.

It is difficult to predict the future course of the Irish oyster industry. However, if it is assumed that the private sector is going to expand and flourish it is possible to predict some of the effects such developments will have on the public sector.

(i) Greater Production

In time it is anticipated that the production of private oyster fisheries will far exceed the current output of the public fisheries (approximately 3 million oysters per annum) as a result of the more intensive and effective cultivation techniques employed.

(ii) Better Quality

The quality of the oysters marketed by private fisheries is currently higher than that of oysters taken from the public fisheries because of the superior standards of cleaning, grading and packing employed. The quality 'gap' is likely to widen unless the fishermen and local buyers cooperate to improve the quality of oysters leaving Clarinbridge.

(iii) Better Marketing

The private sector generally has better marketing machinery than the public sector and can command higher prices for its products. For example, a large proportion of the oysters produced at Clarinbridge and Tralee are sold to local buyers (at relatively low prices), who can dispose of them, after processing, in the more lucrative European markets. The latter mentioned dealers are better able to sell abroad because they can generally guarantee the supply of large quantities of good quality oysters on demand.

In order to compete with this system it will be necessary for the public sector to marshal its effort, by the means described earlier, in order to develop strong, reliable and direct links with the European markets.

(iv) Seed Production

The only apparent advantage that the public sector has over the private sector at the present time is that it can rely to a certain extent on natural spatfalls to maintain its stocks. No private fishery in Ireland yet produces its total seed requirements, although recent attempts to rear spat in ponds have produced encouraging results (Hugh-Jones, pers. comm.).

The only major sources of seed in Ireland are, therefore, the public fisheries, of which the Tralee fishery has been the most prolific in recent years. However, it is illegal to remove oysters of less than 76mm diameter from these fisheries, in spite of the known wastage* of spat which does occur (Chapter IV). It would seem reasonable to suggest that this regulation

*The author estimates that ten to fifteen million spat, attached to commercial oysters were removed from the Tralee fishery in 1971 should be adjusted (for a trial period at first), for the Tralee fishery at least, to allow the local fishermen to collect spat for sale to private oyster farmers or for supplementing public oyster stocks or to allow private oyster farmers to collect their own seed for a fee which might go towards the upkeep of the fishery.

The alternative sources of O. edulis are limited to spat produced in Norway and spat reared artificially in approved hatcheries. The former source is limited and not entirely satisfactory because of the poor quality of some of the Norwegian seed and the difficulty and expense of shipping it to Ireland. Furthermore, Norwegian spat are not proving to be an economic investment in some areas because although they may grow more rapidly at first (Hugman, pers. comm.) they do not 'heel up.' Preliminary growth experiments conducted by the author at Clarinbridge (Table 70) indicate that the growth and mortality rates of Norwegian oysters are unsatisfactory when compared with those of native oysters.

TABLE 70

A COMPARISON OF THE GROWTH RATES OF *OSTREA EDULIS* FROM NORWAY AND CLARINBRIDGE-- MARCH - OCTOBER, 1972

Source	Initial Weight (g)	Final Weight (g)	Overall Mortality %
Norway	1.69	5.34	47
	3.70	6.80	
	5.78	9.58	
	10.05	11.64	
Clarinbridge	1.95	7.57	30
	3.48	8.40	
	6.19	13.50	
	11.50	18.01	

The production of hatchery-reared *O.edulis* has been feasible for some time (e.g. Walne, 1956; 1966). However, the reliable production of commercial quantities of *O.edulis* spat is still in its infancy (e.g. Haywood and Curr, 1970) and, at least for the time being, presents no long-term solution to the problem facing Irish oyster growers. Furthermore, it is unlikely that *O.edulis* will be produced in large quantities, because although it has a high market value the newly introduced Pacific oyster (*Crassostrea gigas*) can be produced more reliably, more cheaply and may ultimately be in greater demand if a market for processed oysters develops (McCarthy, pers. comm.). In British waters this species can reach commercial size (70g) in two to three years (Walne and Spencer, 1971) and may prove to be an attractive proposition for British oyster growers.

Encouraging results are being obtained with the species in Northern Ireland (Parsons, pers. comm.) but as yet no results are available in Eire, where only small quantities have been introduced.

10. The Clarinbridge Public Oyster Fishery and the E.E.C.

At the time of writing no information was available about the effects of Ireland's entry into the European Economic Community on the oyster industry. It is assumed by a large number of oyster dealers that the heavy tariffs imposed on Irish oysters imported into Europe will be reduced over a period of years and finally abolished. Such a reduction in tariffs would enable Irish oyster dealers to increase their prices abroad and improve the competitive position of their goods in relation to French oysters which are not subject to such protective tariffs.

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